The Optacon

THE COVER. Eight-year-old Kevin LaRose, the youngest person using an Optacon of his own, is shown with Mrs. Kathleen Smith of the Lake Washington Special Education Center, Kirkland, Washington, as they participated in the Optacon Teacher Training Seminar sponsored by The Seeing Eye, Inc. at Stanford University August 30-September 9, 1972. (Photo by Zora Norris)

ABSTRACT

THE OPTACON

The blind can read ordinary printed matter directly and independently with the Optacon developed at Stanford under Office of Education support. The Optacon is a book-sized electronic device with a movable camera the size of a pocket knife and a tactile screen the size of a fingertip which presents a tactile image on an array of vibratory pins. The reader passes the camera over printed material with his right hand and with his left index finger feels in vibratory relief the image the camera sees. Experienced Optacon users read up to 90 words per minute, about half their Braille reading speed.

An advanced integrated circuits laboratory at Stanford was required to design and construct the custom photosensors and MOS circuits which make the Optacon possible. The Optacon development in a university environment with faculty and doctoral student staff is a new commitment of advanced technologists to ameliorate a human problem.

A small company formed by members of the research team has produced and distributed 250 units of the 1971 Optacon.

The 1971 Optacon is effective; a better Optacon is planned. A simpler and more rugged Optacon of cigarette pack size is projected which will require only one hand in use.

Final Report

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RESEARCH AND DEVELOPMENT OF TACTILE FACSIMILE READING AID FOR THE BLIND

(The Optacon)

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U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

Office of Education

Bureau of Education for the Handicapped

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION AND OVERVIEW OF THE OPTACON PROJECT

A. The Optacon Concept

One primary problem of blindness is lack of direct access to the printed material of the sighted. Though Braille and recordings are useful to provide information to the blind, the requirement of intermediate translation is an inherently limiting obstacle. The Optacon provides the blind direct and independent access to printed matter.

The concept of the Optacon (for optical-to-tactile converter) is generation on an array of vibratory pins of a tactual image of a printed area about the size of a letterspace. Thus the Optacon is a kind of closed-circuit tactual television system in which the tactile screen, comprised of vibratory pins in a dense rectangular array the size of a fingertip, presents in relief an image of the material seen on a corresponding array of photosensors in its camera. The blind reader uses his fingertip as a tactual retina with which he reads tactually in the same way that a sighted person reads visually; he feels the same shapes the sighted see.

The new technology of integrated circuits and of piezoelectric vibrators provides the implements with which the Optacon can be realized in a personal instrument form. Harnessing this technology to attack the reading problem of the blind has been the aim of the Optacon project at Stanford.

B. The Office of Education Project at Stanford

Prior to the support of the Office of Education at Stanford, several rudimentary tactile screens, each consisting of an array of vibratory pins with each pin driven by a piezoelectric vibrator, had been constructed in a collaborative effort of Stanford University and the Stanford Research Institute. When one of these arrays was driven by a computer to pass letter shapes under the finger of a reader, the readability of facsimile shapes by the blind was verified. Further, a simple form of the Optacon was constructed in which blind students had been able to read typed material from a printed card.

The aim of the Office of Education project was the required research and development on semiconductor and piezoelectric components to realize instruments with which the blind could read directly and conveniently. It was clear that commercial devices did not exist with which a reading aid could be made directly. The Electrical Engineering Department at Stanford had expertise in the area of semiconductor electronics. Our doctoral research program found the R&D project of integrated circuits for a reading aid an attractive opportunity. From the outset the project was conducted with very explicit goals. Usable devices were to be constructed, and these devices were to utilize the most sophisticated electronic structures which would be helpful in construction of the instruments. At the same time, fundamental studies typical of doctoral research were to be undertaken, and the design of the reading aid was to be optimized in the best tradition of a scientifically based R&D operation. Concurrently the instruments produced were to be tested with the blind students already connected with the research program at Stanford.

C. Milestones of the Optacon Project

The high points of the five-year-long program just completed on the Optacon project under Office of Education support are depicted on Chart 1.

Chart 1

MILESTONES OF THE OPTACON PROJECT

Piezoelectric tactile screen invented and constructed	(1963)
Tactual reading of letter shapes (tactile screens operated by computer)	(1964)
First complete reading machine (reading typed cards only)	(1965)
First high resolution (6 × 24) reading aid	(1967)
Initiation of OE Grant	(1968)
Optacon with movable camera and multiplexed electronics	(1968)
Working silicon (Si) integrated circuit (IC) retina	(Apr. 1969)
First portable, personal size Optacon	(Sept. 1969)
10 Optacons in use by Stanford students, SRI programmer, junior high student, Monroe School children	(1970)
Metal-oxide-semiconductor (MOS) IC completed for tactile screen driver (required less power and much less space)	(Jan. 1971)
Smaller Optacon using bipolar retina and MOS screen driver demonstrated (prototype for present production)	(Mar. 1971)

Development and Production at TSI	Research and Development at Stanford University
Telesensory Systems, Inc. formed by Bliss and Brugler to produce 50 Optacons for OE (June 1971)	Advanced Si technology realized at SU; Si gate process, analog shift registers of bucket-brigade and charge-coupled types realized (1972)
S. Brugler and C. Linvill demonstrate Optacon to Rehab. Center in Heidelberg (Oct. 1971)	Self-scanned MOS 6 × 24 Si retina realized (1972)
Schoof uses IBM terminal (Fall 1971) and pocket calculator (HP-35) with Optacon (Summer 1972)	High voltage MOS circuits (up to 150V) realized (1972)
Lutz produces report of San Diego Optacon Project (July 1972)	Integrated construction techniques for piezoelectric tactile screen developed (1972)
TSI produces 200th Optacon (Dec. 1972)	Concept and organization for one-hand Optacon proposed (1972)
13 of 15 of first class of German programmers are employed (Feb. 1973)	

With the initiation of the Office of Education grant in 1968 a comprehensive program to develop the required components for an improved blind reading aid of the same class which had been demonstrated in 1965 and 1967 was undertaken. The earlier rudimentary reading aids made in 1965 and 1967 used individual phototransistors in cumbersome optical systems which were too heavy to be conveniently moved over printed matter. A more convenient movable camera was developed during the first year of OE support, and a multiplexing arrangement was developed in which the electronic circuit was shared by all of the sensors in a given column, greatly improving image quality. A dominant improvement was the construction of a silicon retina, about the size of a capital letter in pica type, which comprised all of the individual phototransistors in a higher resolution 144-element array. The first portable, personal size Optacon was completed in the Fall of 1969, and with it the blind students on the project were able to read at significantly faster speeds. Concurrently the capability of the Integrated Circuits Laboratory grew rapidly, and metal-oxide-semiconductor circuits were produced which simplified greatly the electronics portion of the device. In March of 1971 an Optacon utilizing a bipolar semiconductor retina and an MOS integrated circuit to drive the tactile screen was completed and demonstrated. At that point the Optacon was sufficiently convenient that a field trial supported by the Office of Education was projected.

Production of Optacons in field trial quantities was not suitable for Stanford University or SRI. The Optacon project team at Stanford split into two separate parts with separate functions. Telesensory Systems, Inc. was formed, with Drs. Bliss and Brugler devoting substantially their full time to this new operation, which was to develop and produce the 1971 Optacon (called the R-1 Optacon by TSI). Concurrently in the Integrated Circuits Laboratory at Stanford, research and development projects were continued in the areas which would lead to significantly better Optacons. Communication between TSI and the Optacon research group at Stanford continued with mutual benefit as the 1971 Optacon was put into production. As a result of the effort in the Integrated Circuits Laboratory, simplified circuits have been developed and an integrated construction technique for the piezoelectric screen has been evolved.

At this time Telesensory Systems has produced more than 250 of the 1971 Optacon on which a number of refinements have been made in production. Meanwhile, at the university the concept of a remarkably smaller, simpler and more rugged Optacon--the one-hand Optacon--has been proposed.

Three related proposals for further work on the Optacon have been prepared. One emphasizes developments which will yield a simpler, more rugged device with a higher degree of integration of the semiconductor and piezoelectric systems. Another emphasizes assessment of the psychophysical factors, in particular assessment of the advantage connected with use of the same hand for guiding the device and sensing the tactile pattern. A third proposal relates to the technological problem of developing a new class of complementary metal-oxide-semiconductor (CMOS) integrated circuits, which are required to produce an Optacon the size of a pack of cigarettes, low-powered enough to be run from a single small battery.

D. Structure of the Final Report

The remainder of the final report is divided into two principal chapters. Chapter II provides a chronological account of the five-year OE-sponsored research effort. This chronological account fills in many of the details outlined briefly in Chart 1, "Milestones of the Optacon Project." Through such a chronological account of the Optacon project the continual interplay between fundamental study and instrument development can be perceived. The Optacon project has been an exciting experience to Stanford researchers. Realization of each new semiconductor advance followed the typical number of frustrating failures. Concurrently, the testing of the reading instruments by blind experimenters provided intense stimulation to technologists, who were seeing the effect of their instruments in permitting the blind to do what they have never done before.

The chronological account of the Optacon project provides implicitly the basis for the conclusions, observations and recommendations which are provided in Chapter III. The principal conclusions are that the Optacon presently in production, the 1971 Optacon, is effective as an adjunct to Braille and recordings in the education of the blind. Moreover, developments which have not yet been incorporated into a production device are clearly advantageous, and these will lead to better reading devices.

In its $1.8 million program on the Optacon, the Office of Education has been embarking upon a project unique in the education and welfare sector, the support of technology addressed to a human problem. The principal investigator has drawn certain observations from this experience, and these observations are incorporated into the thesis that the government-university-industry combination is symbiotic in attacking blindness with technology.

Finally the recommendations for further action on the Optacon are given. The recommended actions are to disseminate the current Optacon more broadly to the blindness system and to conduct research in technology and psychophysical factors so that more potent, simpler and less expensive Optacons can be developed.

A set of appendices are provided at the end of the report which provide important details regarding the facilities of the Integrated Circuits Laboratory, personnel lists, thesis abstracts, and published papers related to the work of the Optacon project. The Optacon project has generated a great amount of external interest, and a chronological log of presentations and demonstrations is provided. In one section of the appendix the relationship of Telesensory Systems to the Optacon research group at Stanford University is given in a form which explains the facets of this interconnection and the overlapping responsibilities of the constituencies involved.

CHAPTER II

A CHRONOLOGICAL ACCOUNT OF THE OPTACON PROJECT

A. Progress Prior to the OE Grant (1963-8)

Preliminary research at Stanford Electronics Laboratories supported by the Office of Naval Research had indicated the feasibility of the reading aid conceived by Dr. John G. Linvill* before a first proposal was submitted to the Office of Education. In 1964 a precise 8 × 12 array of piezoelectric reeds for tactual presentation of letter shapes was constructed at Stanford University and operated for reading tests by a small computer at the Stanford Research Institute. (Dr. James Bliss had been experimenting at SRI with air-jet tactual reading for NASA, the U.S. Air Force and several other agencies.)

The next step was research on a photosensor and the electronics required to activate the tactile array by signals generated by the black-white contrast of ink print. The first complete reading aid (Figure 1) was built in the Solid-State Electronics Laboratory at Stanford by doctoral student Richard C. Joy in 1965. The optical system was composed of a section of a microscope, inverted and

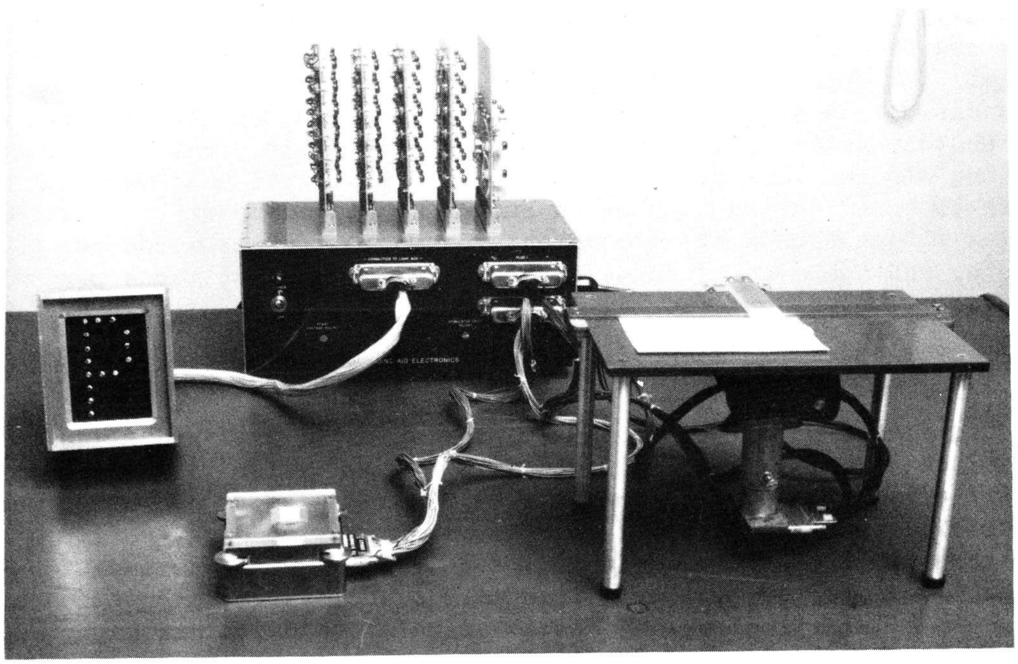

Figure 1. First Complete Reading Aid (1965) - Typed Cards Were Moved Over the Camera Face Down

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* In January 1964 Dr. Linvill applied for a patent on the "Photo-mechanical Dynamic Embosser" which was granted two years later. From the outset the United States Government has had a non-exclusive, irrevocable, non-transferable, royalty-free license to practice the invention.

mounted on a stand. Typed material was inverted over the one-letter-size aperture of the microscope, and the objective lens produced an enlarged image on a 6 × 8 array of discrete phototransistors at the end of the microscope tube. These discrete phototransistors were operated in the charge-storage mode which greatly improved uniformity and yielded signals which were large enough to avoid the necessity for 48 separate amplifiers. Each phototransistor was connected to a different flip-flop (circuit storage element); the latter were mounted on circuit cards above the power supply box, and each activated a different switching transistor which caused a reed in the 6 × 8 array of piezoelectric stimulators to vibrate. The total vibration pattern corresponded to the letter image. (The switching transistors were also connected to a light box which provided a visual image.)

The "first-generation" reading aid shown in Figure 1, besides being cumbersome in size and operation, presented some difficulties in letter recognition which it was thought might be lessened by increasing the number of image points. Subsequent experiments on the tactile screen supported by the Vocational Rehabilitation Administration were run with a 4 × 12 configuration, and 6 × 24 was tentatively settled upon as a suitable number of columns and rows for tactile reading. A second reading aid constructed at SRI incorporated the 144-element array. Its optical sensor consisted of a movable head at the end of a bundle of 144 light fibers, connected at the other end to a set of 144 phototransistors in the electronics box. This first 144-element reading aid enabled the first extensive manually scanned reading tests to be conducted with blind subjects. All four of the participating subjects read at rates greater than 10 correct words per minute, and two read at rates greater than 20 correct words per minute.

B. Initiation of the OE Grant (1968)

The two-year proposal submitted by Professors Linvill and Bliss to the Office of Education on April 18, 1967, aimed for an initial specific goal of construction of five reading devices of sufficient simplicity and effectiveness to give meaningful reading tests. Eventual construction was planned of a larger number--perhaps ten--of improved devices, incorporating more effective implementation of the optics, electronics and tactile stimulators which was expected to result from doctoral dissertation research of Stanford students. February 1, 1968, was the beginning date of the Grant awarded by OE to Professors Linvill and Bliss at Stanford.

1) Mode of Operation of the Project

Work on a number of related goals with different target dates was characteristic of the reading aid project under the OE Grant. Throughout its progress the effort to build the next practicable prototype and hasten its quantity production proceeded side by

side with intensive advanced research toward an eventual ideal device. At the same time reading tests and evaluation of existing models, together with evolution of the most effective training methods, were continuously under way and helped determine the direction taken by the design research. Most of the psychophysical studies in the early period, as well as the work on tactile stimulators and the optical system for a modified version of the first prototype, were done under a subcontract at the Stanford Research Institute, under the direction of Dr. James Bliss with support from Mr. James Baer.

2) Build-Up of the Integrated Circuit Facility

At Stanford Electronics Laboratories in 1968 a primary goal was achievement of a capability for construction of experimental integrated circuits. Professor James Meindl led this effort. One of his first steps was the hiring of an experienced semiconductor engineer, Mr. Jacques Beaudouin, to devote full time to operation of the existing laboratory and its development for the OE project. At that point, two essential items of equipment were purchased: (1) a precision alignment system for registration of silicon wafers and photomasks, and (2) a set of probes for testing devices on a silicon wafer.

The properties of silicon junction photodetectors had been investigated by Dr. J.S. Brugler in his dissertation research with the goal of improving the reading aid's low-light-level performance. Mr. Phillip Salsbury, a doctoral candidate, undertook the construction of a monolithic image-sensing array in which all photodetectors were on one silicon chip. Concurrently, an attempt was made to develop, by stages, a "hybrid" array, with the shorter-range objective of building some usable reading aids for testing by blind students. These custom-made arrays were to replace the first sensing array, which was a closely packed set of 144 Fairchild FPM-100 phototransistors on which the image of a letter was focused by an incorporated lens system and very short light fibers within the reading head, built at Stanford Research Institute under Mr. Baer's direction.

3) Electronics Research

In the electronics system, work by Mr. James Plummer, a doctoral candidate, commenced on multiplexing the outputs of the 24 rows of phototransistors into six parallel channels, potentially effecting a reduction of the number of wires between photosensor array and control electronics from 144 to 10. Before application of this concept to the complete 6×24 system it was tested by breadboarding a prototype system using a 3×8 array of commercial bipolar integrated circuits. The multiplexing improved low-light-level performance by at least an order of magnitude, and channel-to-channel uniformity was several times better. Further circuit simplification resulted from elimination of the flip-flops

which had been thought necessary, because of the short pulse output, for storage of power to drive the piezoelectric stimulators; the capacitance of the latter was found to provide sufficient storage. Also, X-Y accessing of the stimulator array was accomplished by an array of drive transistors which demultiplexed the signals from the photosensor array and provided the power gain. A simple automatic gain control system was incorporated in the electronics to adjust the reference voltage for variations in reflectivity of the reading material. Threshold detecting circuitry was added with much more gain than the flip-flops provided. A new power supply was designed using a dc-dc converter which enabled a physically small toroidal transformer to be used.

4) Stimulator Research at SRI

The 144-element stimulator array built at Stanford Research Institute was improved by a new mounting approach: simultaneous attachment (with epoxy) of 24 elements (piezoelectric reeds--PST-5HN bimorphs--manufactured by the Clevite Corporation) to a single metal support member corresponding to one column. At SRI Dr. Bliss and Mr. C.H. Rogers conducted a new experiment with blind subjects to determine the best stimulator vibration frequency for tactual perception of moving alphabetic shapes. The results indicated that at relatively fast reading rates higher frequencies increased accuracy, supporting an earlier decision to vibrate the stimulators at 250 to 300 cps.

5) Completion and Demonstration of the 1968 Reading Aid

By autumn of 1968 the first improved reading aid (Figure 2) under the Grant had been completed and was being evaluated. A considerable reduction in size had been effected by compact packaging of the electronics, including power supply, on an 8 1/2" × 15" printed circuit board housed in a flat box under the tracking aid for the photosensor array. A new light-box display for visual monitoring was especially fabricated for use with multiplex electronics. Comprehensive reading tests were made with the new "pancake" prototype, and reading speeds up to 50 wpm were attained.

The optical sensor of this model consisted of a closely packed array of 144 commercial phototransistors on which the image of a letter was focused by an incorporated lens system and very short light fibers within a movable reading head. This prototype incorporated many improvements proposed earlier. Multiplexing the system reduced the total number of wires to the electronic circuit from 144 to 30 (one each for six columns and 24 rows). In the circuit further multiplexing enabled all the phototransistor array output information to flow through six channels (one for each column) to six sensitive voltage comparators which converted it into digital form. The simplifications

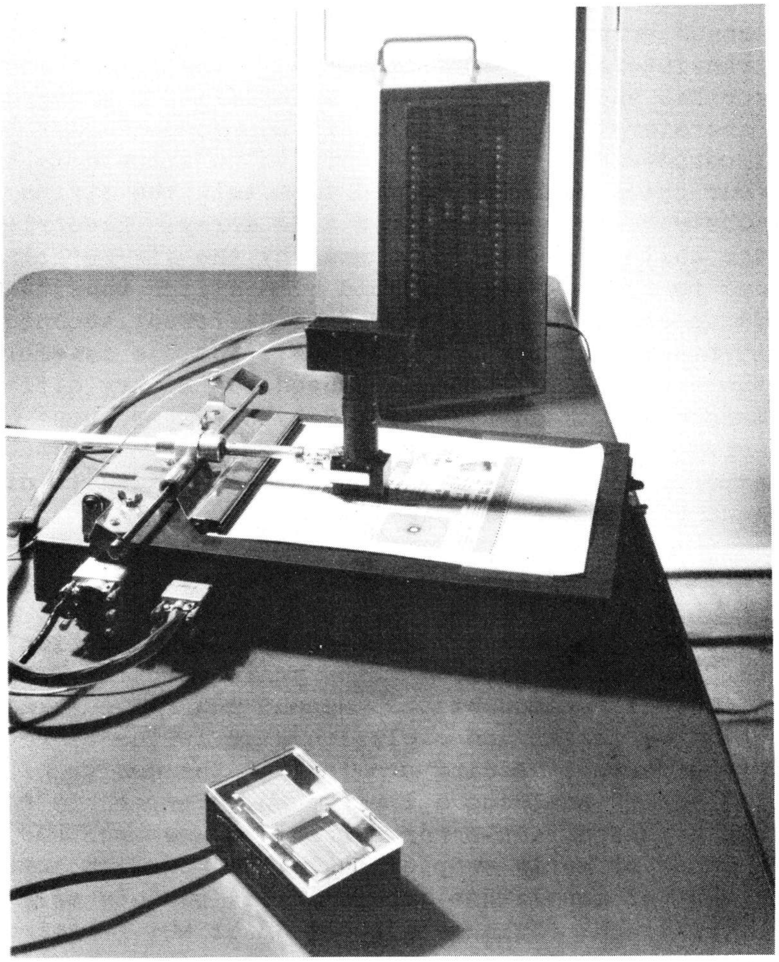

Figure 2. 1968 Optacon With 144-Phototransistor Retina, 144-Element Tactile Screen and Multiplexed Electronics

permitted the electronics and power supply to be contained in a smaller, flat box directly beneath the material being read.

On November 21-22, 1968, a demonstration of this prototype was given at the Office of Education, the Social Rehabilitation Service, and the Office of Naval Research in Washington, D.C.

6) Initial Progress on Hybrid and Monolithic Photosensors

During the summer of 1968 the Integrated Circuits Laboratory had made and tested four different designs of phototransistors which compared very favorably with the best commercially available. This preliminary operation paved the way for construction of more complex devices.

The second stage in the planned development of the hybrid photosensor array involved replacement of the 144 Fairchild phototransistors with 24 silicon chips (measuring 2200μ × 500μ) scribed and diced from 1/4 wafers in the Integrated Circuits Laboratory. On each chip six common collector transistors were incorporated. The chips were to be aligned in six columns of four chips each and bonded to metallized strips on a ceramic substrate to produce the 6 × 24 array. Electrical contact to the collectors was to be made by the six metallized column strips and to the emitters by gold wire stitch bonding of each of the 24 separate rows. A number of different techniques were tried in assembling two dummy arrays. The die assembly procedure and the wire bonding process proved to be very difficult and time-consuming. Meanwhile, Mr. Salsbury's progress on the monolithic array under Dr. James Meindl's guidance had accelerated beyond expectations, and it was therefore decided to discontinue work on the hybrid array.

C. Work of the Second Year on the OE Grant (1969)

The original proposal was revised by a continuation proposal submitted October 23, 1968, for the year beginning February 1, 1969. It cited construction of the "second-generation" reading aid and proposed the design and evolution of a series of reading aids to study the tactual reading problem and the design of producible reading aids. Building a limited number--perhaps ten--for testing and use by blind people was proposed. Research and development was to be aimed at early completion in the Stanford Integrated Circuits Laboratory of monolithic arrays of 144 phototransistors on a single chip of silicon. A long-range study of MOS (metal-oxide-semiconductor) technology and integrated circuits was proposed with the ultimate objective of achieving a portable, battery-powered device.

By April 1969 three improved reading aids of the "pancake" type had been built and were being used in reading experiments with blind students. The reading tests were being conducted under a subcontract by SRI, which also developed an improved reading head for this model and continued to build and modify the stimulator arrays.

1) Completion of the First Silicon Retina

The first monolithic retina (Figure 3) was a significant milestone which was reached by solution of a set of sub-problems. The phototransistor construction capability of the Integrated Circuits Laboratory was extended to include the critical isolation diffusion step. The resultant isolated bipolar phototransistors were the building blocks of the monolithic array (the silicon retina). Each had an active area 100μ × 190μ (after reduction), and they were spaced at 250μ intervals horizontally and 125μ vertically on the silicon chip. For initial tests several half-arrays of these devices were produced. They were successfully operated as

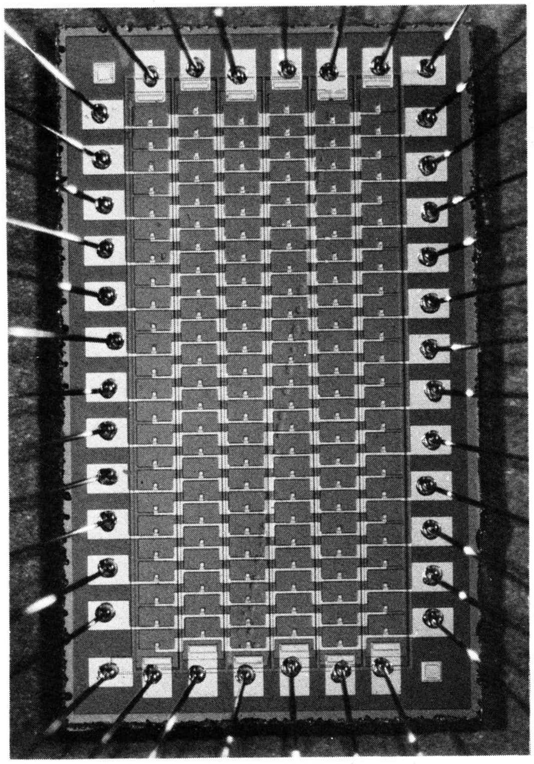

Figure 3. Photograph of the Bipolar Monolithic Photosensor Array - The Silicon Retina (Each of the 144 phototransistors is 6 × 12 mils in size.)

charge storage photodetectors over a wide range of light levels. Next, techniques were developed by Dr. Josef Berger to process photo masks for a full array with the reduction camera that had been designed for the half-size area, and a full array was completed and tested. The unforeseen problem of formation of an electrical channel across the surface of the p-type isolation diffusion, causing shorts between adjacent collector regions, was solved initially by biasing the substrate to -10 volts and avoided in subsequent arrays by creation of a "channel stopper" structure during the base diffusion step. Tests of several arrays from the first fabrication run showed that the phototransistors were of higher quality than any previously made. One of these arrays was installed in one of the reading aids of the type shown in Figure 2.

Revised dimensions for future runs of the monolithic bipolar phototransistor array (with elements spaced at 300μ horizontally and 150μ vertically) were adopted to allow the variable magnification optics being developed at SRI to operate at unity magnification near the center of the desired range. In addition, the masks for the new array were designed with staggered columns to improve resolution. (See Figure 3.)

2) The 1969 Optacon*

The first prototype of a new low-power battery-operated Optacon (designated S-5 in the serial numbers of OE reading aids) was completed on September 1, 1969. (See Figure 4.)

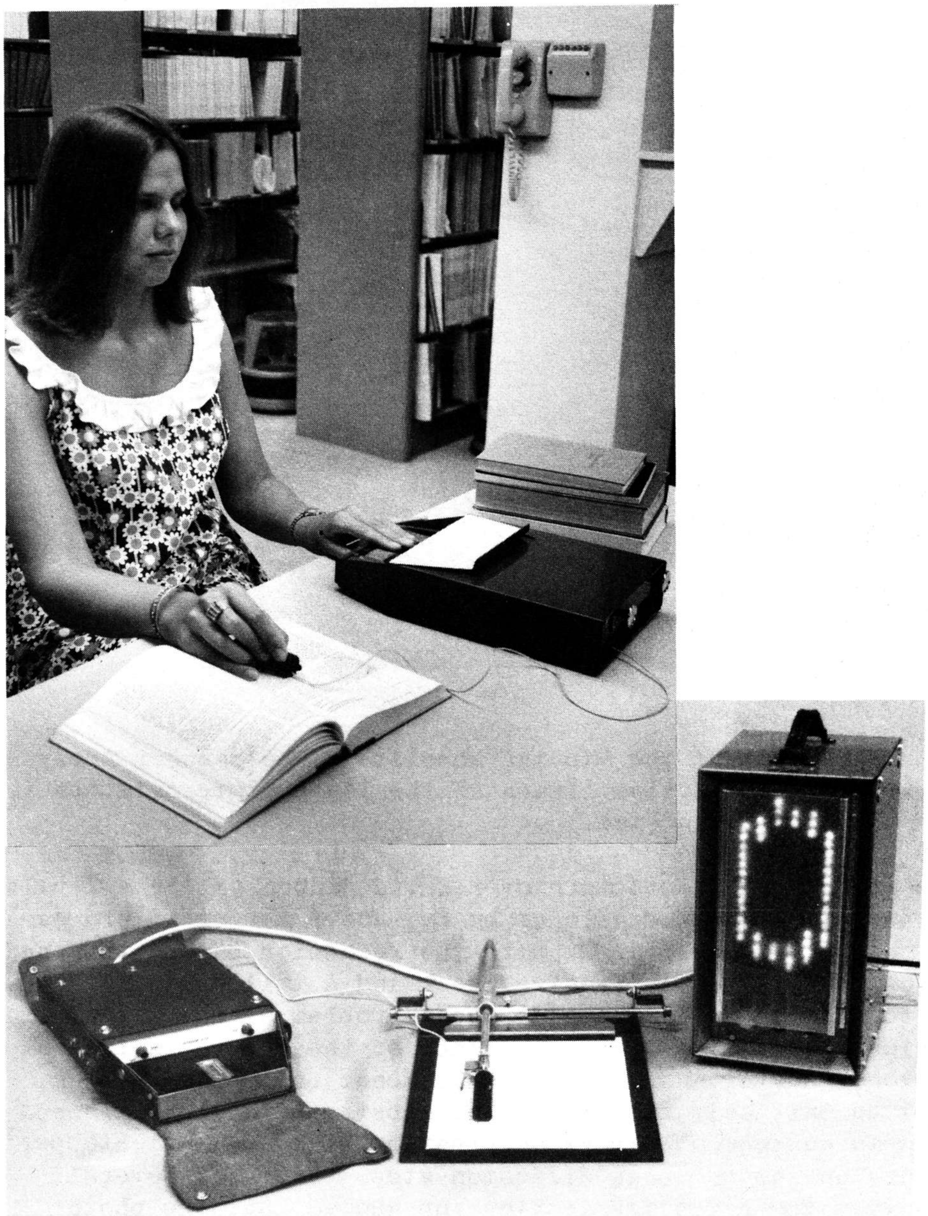

Figure 4. The 1969 Optacon - The First Portable, Battery-Powered Reading Aid

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* Beginning in late summer the acronym "Optacon" (for optical-to-tactile converter) began to be used in reports and in news releases as the name of the reading aid.

This device was portable and completely self-contained in that it combined the stimulator array, the electronics, the batteries and a special storage area for the camera in a single package measuring 13 1/2" × 8" × 2 1/4". The total weight of this Optacon in its sturdy leather carrying case was 9 pounds. The smaller, lighter reading head designed by Dr. Bliss and Mr. Baer at SRI for the new bipolar monolithic retina had a low center of gravity because of its folded optical system, which made it easy to guide without a tracking aid. Its new variable magnification feature enabled almost any size print to be read. Six single-transistor preamplifiers, placed as close as possible to the array columns, provided a low impedance signal source and improved low-light-level performance and noise immunity. A considerable saving in power consumption was realized by simplification of the automatic threshold circuit. Other improvements were elimination of many electrical connections through the use of series-poled bimorphs in the tactile array and placement of the drive transistors closer to the bimorphs. This low-power electronics design (a joint effort by Dr. Brugler and Mr. William Young) made possible about 12 hours of sustained operation from four 1.2V NiCd batteries, with a dc-dc converter generating the required 15V and 60V. During battery recharging the circuitry permitted simultaneous use of the ac source for operation of the Optacon.

3) Improvements in the IC Laboratory

Parallel with construction of a new model of the Optacon and evaluation of reading results with models already built, a new long-range investigation began into the development of MOS (metal-oxide-semiconductor) photosensors for the camera and custom-designed integrated circuit chips for the electronics system, with the goal of further reduced size and power consumption in a future Optacon.

Problems encountered in processing monolithic photosensor arrays and testing electronic circuits, together with anticipated requirements of the projected MOS technological developments, prompted the acquisition throughout 1969 and early 1970 of additional laboratory equipment as follows: a quartz bidistillation unit with a capacity of 1200 cc/hour to provide the highly purified distilled water needed in the manufacture of MOS image sensor arrays, a vac-ion evaporation and sputtering system (purchased with NSF capital funds), an environmental oven for temperature testing of circuits and devices, a new system of diffusion furnaces and oxidation furnaces, a silicon dioxide vapor deposition system and an ultrasonic wire bonder. At the beginning of 1970 the Integrated Circuits Laboratory was enlarged and rearranged for greater efficiency. (An illustrated description of the present Laboratory constitutes Appendix I.)

D. The Third Year of the OE Project (1970)

The continuation proposal dated October 24, 1969, sought additional support for improvement of the design to make possible reading speeds greater than 50 wpm, to make it convenient as a personal instrument for the blind student, and to make it suitable for production in usable quantities. Production of eight models of the low-power portable Optacon was expected by January 31, 1970, and training and testing of blind subjects at Stanford would meanwhile utilize the three older "pancake" models, which were being modified by fitting with smaller optical sensors incorporating the new silicon retina.

1) An Initial Field Trial of the 1969 Optacon

By January 1970 six more Optacons (S-6 through S-11) essentially identical to S-5 (Figure 4) were assembled and made available to blind readers for regular use. Model S-12 was completed after temporary use of its tactile array as a "slave" in design tests and, like the others, assigned to a blind user. Because of stepped-up training activity, three laboratory oscilloscopes were adapted (by means of a simple low-cost converter) for the task of visual monitoring which previously had been done only by the more expensive and complex light box of 144 neon lamps driven in parallel with the tactile stimulators. Also, a new training aid system was completed and interfaced with an ordinary audio magnetic tape recorder to present material to an Optacon at controllable reading speeds ranging from 2 to 200 wpm.

In the spring of 1970 Miss Carolyn Weihl of SRI conducted a successful experiment in Optacon reader training of six blind students of different ages at the Monroe Elementary School in Campbell, California. By summer five of the people who had been assigned Optacons for home use were able to read easily at more than 40 wpm. (Candy Linvill, who had been using the reading aid since the first prototype was built, had achieved a reading speed of 65 wpm.) One of the people with an Optacon, Miss Susan Melrose, a Stanford student, taught beginning Optacon reading to a group of blind high school students in a seven-week summer institute in San Diego, California. As more people were trained, a collection of text material for building reading skill was gradually being assembled and revised. For beginners the alphabet was divided into groups of letters, beginning with the five letters chosen by experienced readers as the easiest to recognize. With the second group of letters, simple words using the ten letters learned thus far were presented. As the letters became more difficult, only three or four at a time were added; words and sentences containing the cumulative alphabet at each point formed a major part of the exercise.

2) Progress on Supporting Semiconductor Research

Laboratory investigation of several aspects of integrated circuit technology guided the continuing development. In 1967 Gary pointed out in his dissertation that spectral responsivity of photodetectors should correspond to that of the human eye to provide the greatest contrast between inked and non-inked portions of an image since inks are designed to look black to human viewers. For the problem of contrast optimization, Mr. H. Landsman constructed a test instrument, with assistance from Mr. Young, to measure spectral responsivity of silicon photodevices, especially p-n junction photodetectors.

Another project centered around a new bipolar device which was distinguished by a diffused ring around the emitter and called a field-effect modified transistor. The FEM phototransistor was evaluated by Mr. R.A. Nordstrom in his dissertation research and found to have a greater responsivity than the conventional type, as well as smaller effective collector capacitance. A related device--a silicon junction field-effect photodetector--was suggested and tested by Mr. S.G. Bandy as reported in his doctoral dissertation. While attempted use of FEM devices in an image sensor array for the Optacon was unsuccessful because of the limited photoengraving capability of the Stanford facilities at that time, the possibility of future applications remained.

The development of MOS photodetectors experienced a decided impetus with Mr. James Plummer's Ph.D. dissertation research. An 8 $\times$ 3 MOS self-scanned image sensing array was connected in a preliminary laboratory model reading aid to two custom MOS circuit chips and three custom MOS self-scanned drive circuit chips, all made in the Integrated Circuits Laboratory. After testing of this model a number of changes in the custom integrated circuits were made, and two more 8 $\times$ 3 models were assembled and evaluated. Additional monolithic MOS circuits designed and constructed were a clock circuit and a preamplifier (a planned intermediate step in development of a monolithic operational amplifier). Improvements in the MOS processing technology were achieved by use of P_2O_5 stabilization and by growing a thin oxide over the photosensitive diodes.

A parallel project was Mr. Roger Melen's dissertation research on applicability of charge-coupled devices (CCD's) to the Optacon image sensor. CCD's are semiconductor realizations of analog shift registers fabricated in the form of linear arrays of closely-spaced MOS capacitors. They feature reduced area and offer lower manufacturing cost than many other types of semiconductor devices. Comparison of an 8 $\times$ 3 CCD sensor constructed in the Laboratory with Plummer's 8 $\times$ 3 MOS sensor revealed that while the CCD's inherent simplicity and symmetry of construction would make it possible to build denser and

larger arrays and would eliminate the problem of spike noise, the MOS device could detect lower light levels and more easily perform auxiliary circuit functions; moreover, increased density and size in the Optacon application were precluded by current design constraints. Ultimately the practicability of a CCD sensor will be determined by further instrument construction and evaluation.

3) An Experimental Optacon for SRS With a Wider Aperture

The idea was frequently expressed that a wider field of view than the one-letter aperture of the 1969 Optacon would permit tactual reading at a faster rate. Mr. Jon Taenzer's dissertation* research into psychophysical aspects of visual and tactual word reading used computer-generated English text moving across visual and tactile displays. The displays had 12 × 12 elements; varying window widths and degrees of resolution could be produced. Preliminary results indicated that for narrow window widths the speed of both visual and tactual reading was proportional to the aperture width.

With the density of vibratory points of the 1969 Optacon, the space of one fingertip was required for a letter. A simple suggestion was to use two adjacent fingers and to tactually observe twice as wide a field. A special two-finger Optacon was constructed at Stanford Research Institute under a grant from the Social and Rehabilitation Service. The "jumbo" Optacon, S-14, had a double-width camera and a double-width display, half for one finger and half for an adjacent one. Unfortunately, no blind reader read faster with the two-finger Optacon than with the standard one.

In subsequent tests on SRI's LINC-8 computer, involving the six most experienced Optacon readers, the use of a 16 × 12 array (16 columns, 12 rows) for two-finger sensing revealed no improvement in performance over the one-finger display. In addition to the S-14 Optacon with its double conventional array for two fingers, SRI made a separate 12 × 24 "slave" array to be driven from S-14. The "slave" array had twice the conventional density so that two letters could be presented to one fingertip. Again

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* Taenzer's dissertation also developed a model of the human information processing mechanisms which describes visual and tactile reading performance under subject-scanned and fixed-rate stimulus presentation conditions. The essential difference between visual and tactile reading was shown to be a perceptual limitation of 1.5 letterspaces tactually (at least within the context of the displays and subjects used), while the normal visual limit is estimated to be from 5 to 7 letterspaces. Taenzer's thesis also revealed new insights into the cognitive processes involved in reading which are of general importance.

no significant improvement in reading performance resulted, but it is not clear whether small letter size or the lateral compression of letters or other effects are at fault.

It is clear from this experience that further well-designed psychophysical experiments on tactual reading need to be made. The processes and limitations of perception of tactile symbols and messages and the factors which limit the speed of their acquisition simply are not known at this point. This information is crucial in the long term.

As an addendum to the note on the SRS project, the results of other work with other sponsors should be acknowledged here. Related projects--both engineering and human factors oriented, under various sponsors--had a bearing on the reading aid development. Having supported solid-state electronics research for some years before 1964, when G.J. Alonzo's Engineer's thesis "Development of a Piezoelectric Dynamic Embosser for Use as a Reading Machine" was completed, the Office of Naval Research continued to sponsor basic research such as Richard Joy's investigation of charge storage mode operation of phototransistors, H. Ruegg's work on photodiodes, P.A. Gary's research on silicon photosensors for the reading aid application and K. Andres' analysis of MOS structures. J.W. Hill's dissertation on "The Perception of Multiple Tactile Stimuli" was a product of NIH-sponsored studies, and Mr. Ray Shepard's Master's thesis on acoustic and tactile short-term memory reflected School of Education interest in this area. Dr. Brugler's dissertation project--low-light-level limitations of silicon junction photodetectors--was supported by the Joint Services Electronics Program, as was David Bigelow's later work on "bucket-brigade" MOS analog shift registers.

Collaboration with other interested University departments should be mentioned. Professor Robert Calfee of the School of Education offered to participate in reading aid evaluation and development of teacher training methods. Dr. Norman Mackworth, a research associate in the Psychology Department, was assigned an Optacon for reading tests. The reading head used on the S-15 prototype was the outcome of a design project of a Mechanical Engineering class taught by Professor Henry Fuchs. Although the class had originally undertaken study of possible modifications of the machined part of the S-5 reading head to facilitate quantity production, they eventually redesigned the entire probe. The Fuchs probe had a simpler means of varying lens magnification and a diffuse "white box" page-illumination arrangement which made lamp adjustment unnecessary and improved page illumination so that the camera still worked when lifted above the page. Separate modules were devised for the lens system and for the retina and preamplifier.

E. Fourth Year of the OE Project (1971)

1) The 1971 Optacon

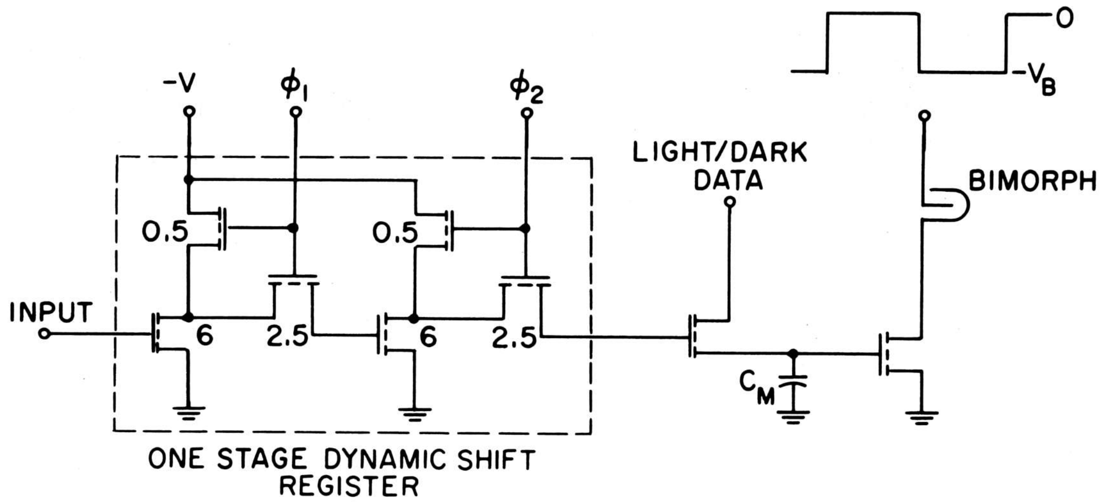
Work on MOS integrated circuits, which had been under way in parallel with the construction of refined versions of the 1969 Optacon, made possible a smaller Optacon in March, 1971. (See Figure 5.) This model is a hybrid device, utilizing a bipolar retina and custom MOS circuits in the electronics section.

Figure 5. The Model S-15 Hybrid Optacon - 1971

With the building of the S-15 Optacon a significant milestone was reached. While an improved version of the bipolar retina was retained in the probe, two MOS driver circuits were adapted to provide the scanning pulses (replacing 12 TTL integrated circuits), 12 MOS driver chips (Figure 6) replaced the 144 discrete transistors and 144 resistors used in prior models to drive the stimulators, and very low power commercial complementary MOS circuitry was used for the remainder of the electronics. The hybrid Optacon was considerably smaller than the earlier models, measuring 8" × 6" × 2" and weighing only four pounds (including the leather carrying case). (See Figure 7 for a size comparison of S-13 and S-15.) The 6 × 24 tactile array, being somewhat smaller than its predecessors, had greater density. It was fabricated in a new, easier way, with all six columns cantilevered from one side rather than three from either side, and its drive voltage could be regulated by the user. Two new operational electronic functions added to this model were a signal polarity reversing switch which allowed white-on-black letters to be read and a built-in automatic slaving

connection for a second Optacon or an Optacon Training Aid. An improved visual display box for use with this model was constructed by using light-emitting diodes instead of neon lamps.

(a)



(b)

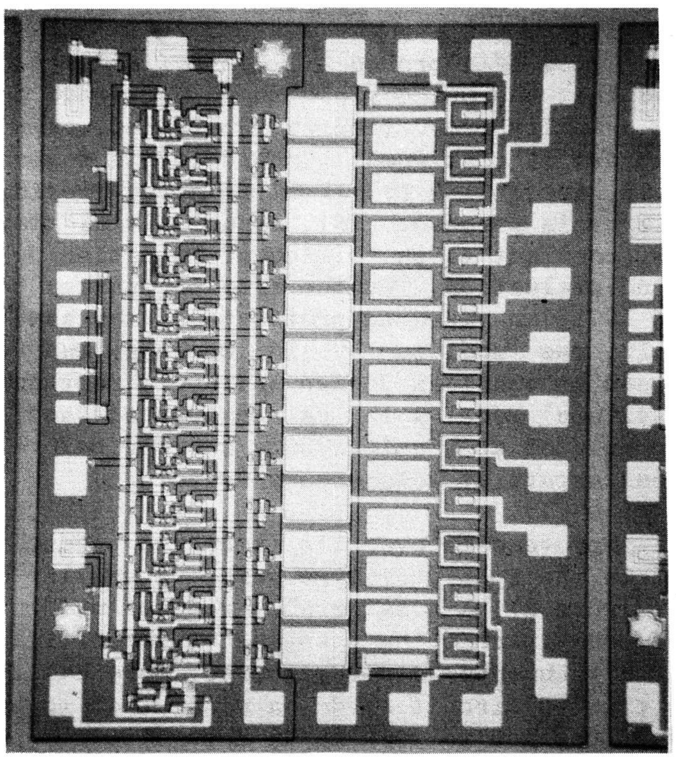


Figure 6. (a) Circuitry for 1/12 of Bimorph Driver Chip
(b) Photomicrograph of Monolithic Bimorph Driver Chip

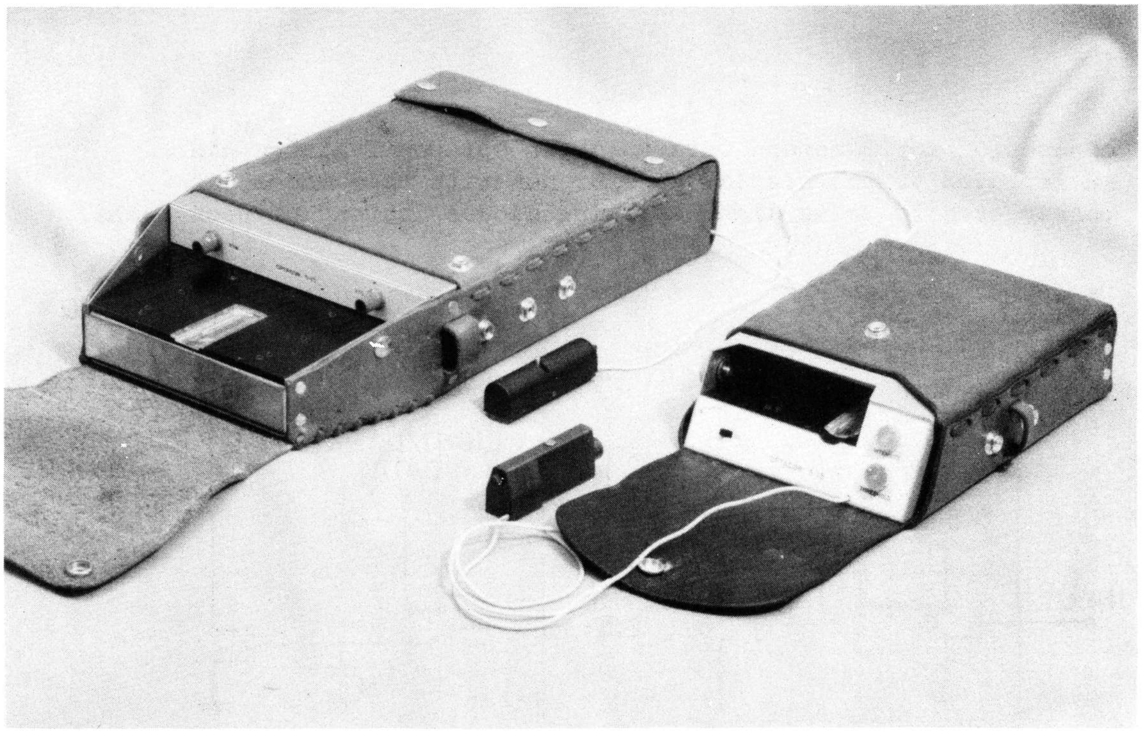


Figure 7. Model S-15 (1971) Compared to 1969 Optacon

2) Formation of Telesensory Systems, Inc.

Now that such a greatly improved and compact model had emerged, it was decided that the Optacon had reached a stage of development at which quantity production was justified, even while efforts to improve it continued. In mid-1970 a company, Telesensory Systems, Inc., with Dr. James Bliss as President, had been formed for this purpose. TSI, as an initial step, proposed to build under contract to the Office of Education 50 Optacons for testing and evaluation. By the time production began, in the summer of 1971, an improved prototype of the same size, designated S-16, the "modified hybrid" Optacon, had been built at Stanford, and it was this design which was reproduced as Telesensory Systems' Model R-1. As a matter of fact, the S-16 Optacon was completed at Stanford only shortly before its production counterpart at Telesensory Systems.

The principal improvements over its immediate predecessor which were realized in the S-16 prototype were: a smaller camera with fewer parts (Figure 8), a considerably reduced machining cost and a new bayonet-mount permitting changing of the retina module to other modular attachments; a reengineered, more easily fabricated chassis; new printed circuit cards, a minimum of internal connectors, a circuit breaker to replace an internal fuse, and modular construction of the electronics package for easy servicing. One change was made in the tactile array--a return to the earlier dimensions and density--but the off-resonance vibration and adjustable drive voltage were retained.

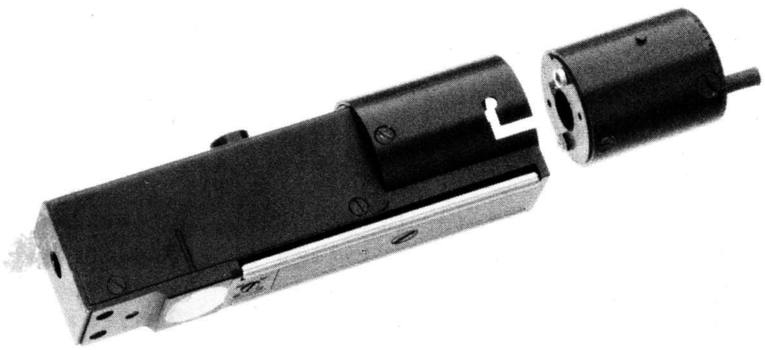


Figure 8. The Improved Optacon Camera

The Qualidyne Corporation was enlisted by TSI to produce the bipolar retina and was given extensive technical assistance by the Integrated Circuits Laboratory. Later, similar cooperation was extended to Teledyne Semiconductors in producing the improved bipolar retina, and to Nortec Corporation in the manufacture of MOS transducer drive circuits (for which a set of masks was obtained through Microfab). Packaging and bonding of the drive circuits was finished at American Micro-Systems, Inc.

3) Preliminary Dissemination and Training With the 1971 Optacon

From the cumulative results of experience with Optacon instruction materials Miss Carolyn Weihl had developed two different sets of 16 lessons for comparative tests, as well as a set of speed-building exercises, as a tentative training package. The first blind person to be trained with this material was Henry Schreiner, a University of Oklahoma sophomore attending the 1971 summer session at Stanford and awaiting delivery of his own Optacon (for which funds had been raised by the Presbyterian Church in his home town, Midland, Texas). He progressed through the 16 lessons in 12 hours of training, and after 20 hours achieved a reading speed of 10 wpm (30 wpm by the end of the summer). Since evaluation by teachers new to the Optacon was particularly desired, the second preliminary test of the method was with two student-teachers at San Francisco State College, each of whom was training a blind high school student in a four-week program. On the basis of these summer training experiments, the text was revised and supplemented, and again used in September for an intensive two-week training program with adult students at The Seeing Eye, Inc. After these tests, changes made in the training package resulted in more emphasis on lower case letters and their earlier introduction, exposure to different type fonts, inclusion of more numbers and mathematical symbols, and a reduction in the number of Stage 1 lessons to permit reading of more meaningful material sooner. The lessons were printed and assembled into loose-leaf manuals.

Mr. Loren Schoof, for several years connected with the Optacon project as a blind subject, joined the staff as a research associate in 1971. Among his contributions were preparation of

introductory lessons on mathematical symbols and types of notation used by computer programmers but not covered in the normal lesson set, and evaluation of devices developed for use of the Optacon with the computer.

The first issue of the Optacon Newsletter had been sent out in November 1970 to a mailing list of 250 people who had requested to be kept informed on progress on the Optacon. The second edition of the Optacon Newsletter was mailed in November 1971 to a growing list of 350 interested parties. It reported that about 20 blind people had worked with the Optacon in the research program, and that about 10 had Optacons for their own personal use. The availability of the Optacon through TSI was pointed out, the price mentioned ($5000), the status of training plans discussed and possible sources of funds for subsidization of Optacon purchases suggested.

F. Fifth Year of the OE Project (1972)

While the 1971 Optacon has been in the interactive process of production and refinement at TSI, research and development efforts at Stanford University have continued. The aim is to provide means for better, more rugged Optacons which are easier to produce.

1) Research Progress on MOS Circuits

With the all-MOS Optacon as a goal and a 24 $\times$ 6 MOS retina yet to be produced, one of the 8 $\times$ 3 MOS retinas in the Laboratory had been further optimized by adding interlaced row scanning and synchronization outputs. Next a self-scanned 16 $\times$ 6 array of MOS photosensors was completed as an intermediate step. Early in 1972 the 24 $\times$ 6 aluminum-gate self-scanned MOS retina was produced (Figure 9) through the combined efforts of Mr. Shigeharu Horiuchi, Mr. Melen and Dr. Plummer.

In developing the electronics to interface this retina with the tactile array, the research team found that too large a power drain resulted from conversion of the serial outputs to parallel operation of the driver circuits. Yet parallel outputs could not be incorporated on the MOS retina by means of aluminum-gate technology without an excessive increase in spike noise. The initial attempt at solving this problem was construction of a 4 $\times$ 11 self-scanned silicon-gate MOS retina with parallel readouts. Dr. Melen, Mr. Horiuchi and graduate students Ian Bennett and Krishna Saraswat joined the long-range research on silicon-gate MOS technology initiated by Dr. Berger which promised further simplification in addition to reduction in noise level. (Mr. Horiuchi returned to Japan in October, and Dr. Melen assumed leadership of this effort when Dr. Berger left Stanford for Hewlett-Packard.) A reliable p-channel Si-gate MOS technology was established and immediately applied to the development of a high-voltage, high-speed device (the floating-gate, high-voltage MOS output transistor) for use in the bimorph driver circuits--a dissertation research project undertaken by Mr. Krishna Saraswat.

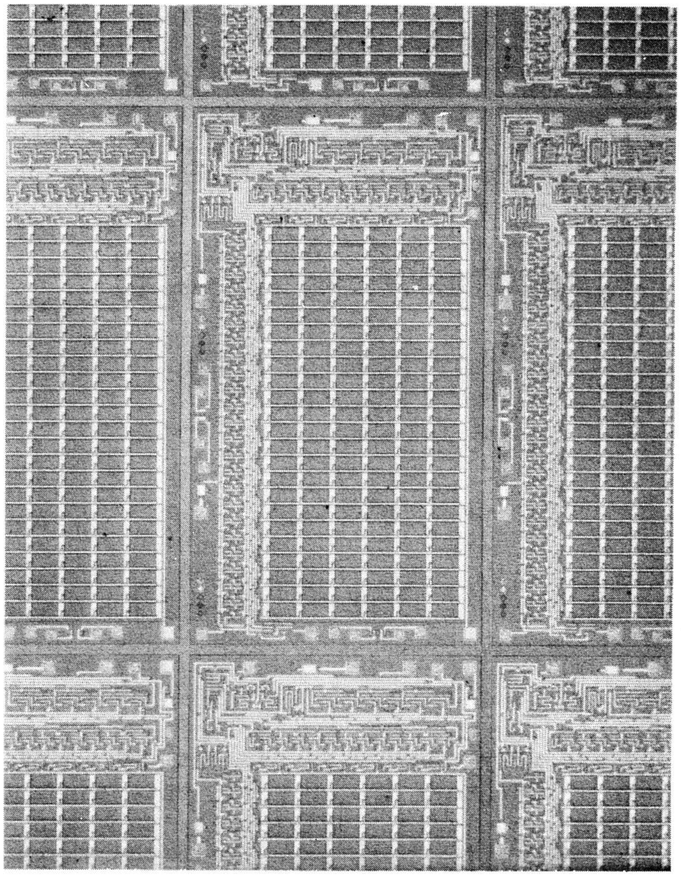
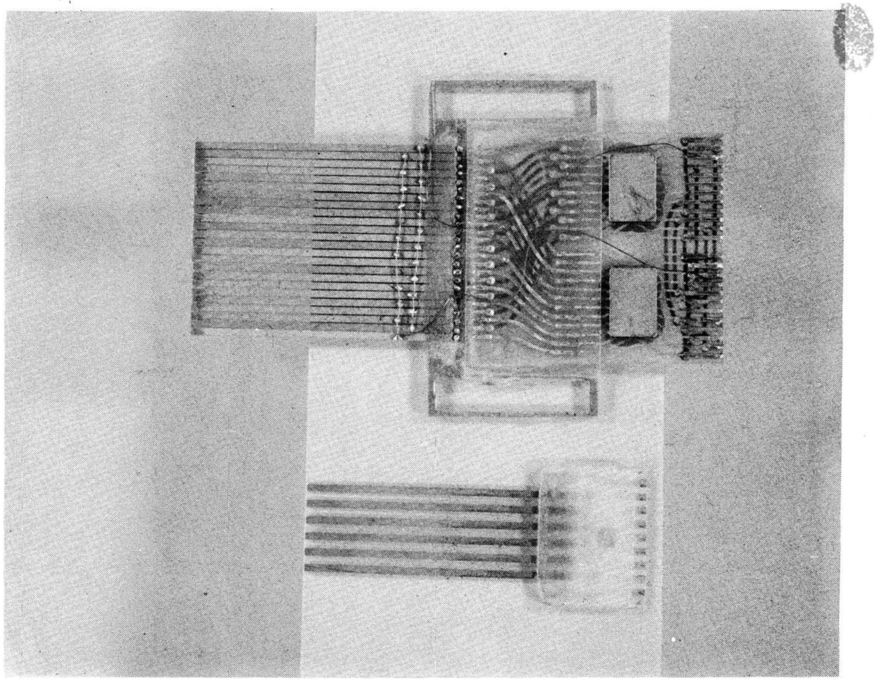


Figure 9. MOS Image Sensor With Scanning Circuits

2) Research on the Tactile Screen

Effort at Stanford to develop a more rugged and easily manufactured tactile array was intensified under the direction of Dr. Max Maginness, and related dissertation topics were undertaken by Messrs. Chi-Shin Wang and Tushar Gheewala. Attempts to improve the current array assembly were closely coordinated between the Optacon manufacturing facility of Telesensory Systems and the Stanford group. With the help of Mr. Paul Jerabek, a highly skilled technician on the project from mid-September on, a significant advance was accelerated by use of a "row-organizing" approach to assembly of the array which immensely simplified the electrical wiring required (Figure 10).



Top Present assembly of each 24-element column of tactile screen. Vibrators are on left, interconnection board and support in middle, individually packaged drive circuits on right. Note especially the large number of soldered connections. Six of these units make a complete array.

Bottom Prototype six-transducer unit embodying some of the techniques proposed for further development. Vibrators are on left; circuit chip is visible through encapsulation on right.

Figure 10. Present Transducer Array and Prototype of Improved Design

3) Proposed One-Hand Optacon and Its Simulation

In July of 1972 Dr. Harry Garland joined the Optacon group in order to conduct reading performance studies and psychophysical research. Such work had previously been carried out under a subcontract by the Stanford Research Institute. Dr. Garland suggested that the Optacon could be more effective if the camera and tactile screen were incorporated into a single,

hand-held unit. Drs. Melen and Maginness investigated the feasibility of such a "one-hand" Optacon and concluded that it could indeed be built using CMOS (complementary metal-oxide-semiconductor) integrated circuit technology. Work was begun on a prototype one-hand Optacon. To determine whether it might be more difficult to scan reading material with a probe larger by virtue of carrying the tactile array and miniaturized electronics with it, a weight machined to the proportions of the proposed device was mounted on Mr. Schoof's Optacon camera. His reading performance was not affected by the increased weight and size.

Complementary metal-oxide semiconductors, so called because elements of opposite polarities (p-channel and n-channel) are incorporated in the same device, represent a technology which can effect a considerable power saving while increasing high-voltage capability of integrated circuits. It has been estimated by Dr. Melen that the degree of mastery of silicon-gate CMOS technology necessary to produce the one-hand Optacon could be attained within two years. Two Ph.D. candidates, Mr. Richard Blanchard and Mr. Gerald May, are beginning work in this research area. Models depicting device and circuit operation are being studied as a necessary preliminary to construction of the first large-scale integrated circuit incorporating an 8×3 array of photosensors on the same device with the CMOS electronics.

In order to test the concept of the one-hand Optacon, two related tasks have been undertaken. One is to complete construction of the tactile screen of the one-hand structure with an integrated transducer array as shown in Figure 10. The tactile screen will be so designed as to be operable from a nearby 1971 model Optacon. The camera of the 1971 Optacon will be used as the camera of the simulated one-hand Optacon. This arrangement is already in construction and is shown in Figure 11.

Concurrently work on the necessary CMOS integrated circuits for a self-contained one-hand Optacon has been proposed.

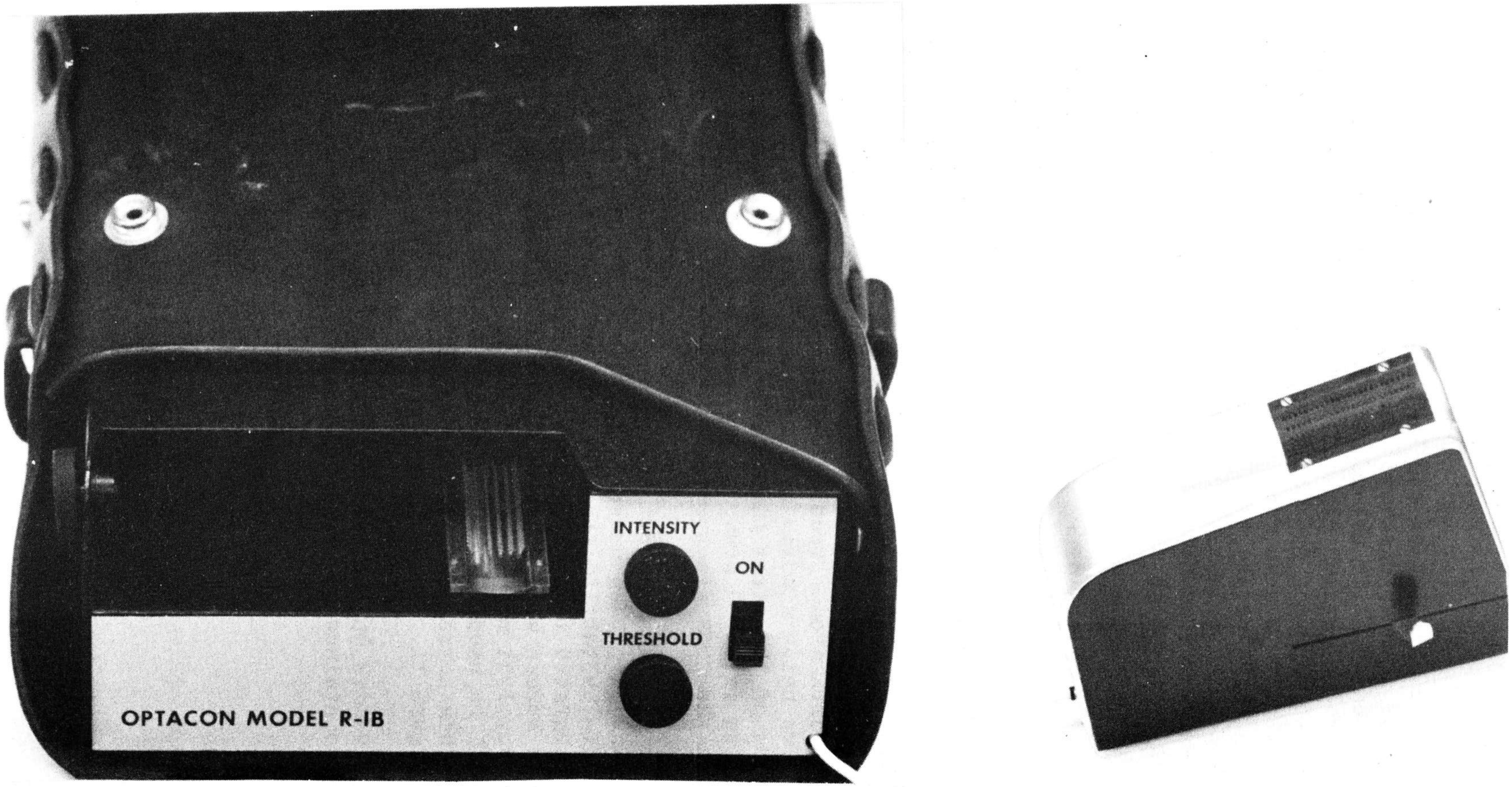


Figure 11. Simulated One-Hand Optacon

(In simulation studies the one-hand structure will be placed over the camera of a nearby 1971 Optacon. Its screen will be driven by the electronics section of the 1971 Optacon. Ultimately the camera and electronics will be integrated into the small structure shown.

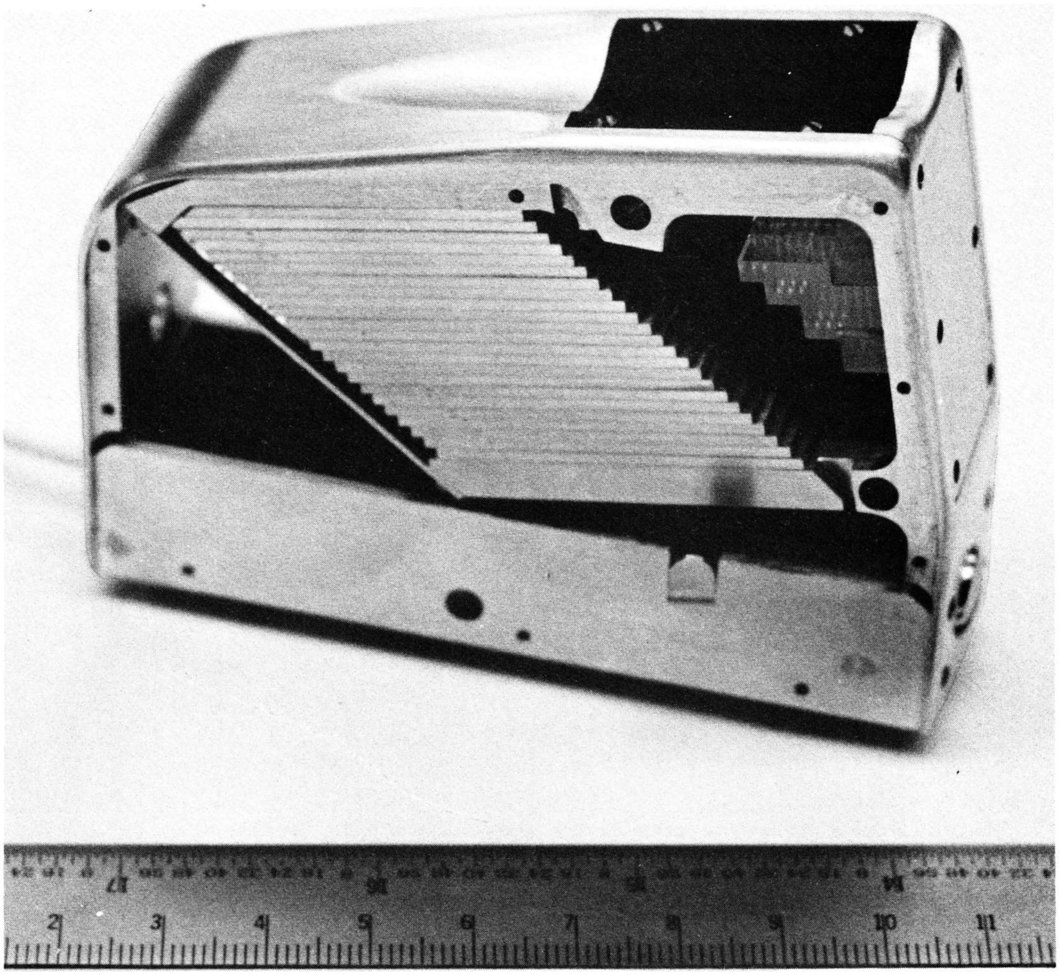


Figure 12. One-Hand Optacon Showing Construction for Integrated Transducer Arrays (see Figure 10)

CHAPTER III

CONCLUSIONS, OBSERVATIONS AND RECOMMENDATIONS

Conclusions

A. The 1971 Optacon Is Effective

1) The Optacon Gives the Blind Independent Access to Print for Personal Use

Blind users make direct use of printed matter without translation with the Optacon first demonstrated in March 1971 to OE and now in production with refinements by Telesensory Systems, Inc. To these users the Optacon permits increased freedom from reliance on other people or services for direct personal reading. They become effective and independent in a new measure. Though the reading speed with the present Optacon is limited to half Braille reading speed, there is an advantage since one person and not two is involved in the task. The dependency of the blind is reduced. For blind students and professionals the present Optacon gives contact with a class of reading matter heretofore unavailable to the blind. It is an important adjunct to Braille materials and tapes currently available and broadens the educational and employment horizons for the blind.

2) The Optacon Makes the Blind More Employable

The Optacon is particularly advantageous in its use with computer terminal print-outs. With the Optacon the blind computer programmer utilizes the computer terminal in virtually the same way as a sighted person. In the Rehabilitation Center at Heidelberg blind computer programmers have been educated with the Optacon. There, with the introduction of the Optacon the use of Braille print-out for computer programmers has ceased. To this point 37 Optacons have been ordered, and the first class of 15 has been graduated. Of that class, 13 were employed shortly after their graduation.

The Optacon with a special camera attachment is directly usable with an electronic pocket calculator, such as the HP-35. The combination of Optacon and HP-35 provides facility in technical computations heretofore unavailable to the blind.

Blind individuals, including administrators, teachers, computer programmers, scientists, lawyers and secretaries, feel that the Optacon has made their abilities and skills more competitive in a sighted world--to such an extent that they have committed their own personal funds to Optacon purchase.

3) The Optacon Gives the Blind a Sighted Perspective in Special Reading Tasks

The Optacon enables performance close to the sighted level on special reading tasks. In the study of mathematical material, direct reading of equations and symbols gives the blind a sighted perspective. The ease of understanding material in which the configuration of expressions conveys added significance is much improved over Braille or spoken recordings. The education of the blind in mathematical material is greatly facilitated by the Optacon.

4) The Optacon Broadens the Educational Horizons of the Blind

Education of the blind is presently constrained by the difficulty of delivering readable materials. This constraint is becoming more severe with the trend toward integration of blind students into ordinary schools and with the reduction in the number of blind students resulting from better medical knowledge. The Optacon can open the door to the instructional material of the sighted from the primary grade students beginning to learn to read to blind university students pursuing advanced study in mathematics, sciences, foreign languages, law, etc.

In the San Diego Optacon Project, 1971-73, funded under ESEA Title VI-B, five blind high school students demonstrated the effectiveness of the Optacon in the school situation. In addition, this project illustrated that the chances for development of successful Optacon reading skills are greater in the school situation than in later life.

B. Better Optacons Can Be Made

1) Technological Improvements Will Make the Optacon Simpler, More Rugged and Less Expensive

Research and development conducted during the last year on piezoelectric stimulators for the tactile screen have produced an entirely new fabrication technique for the tactile screen. With this development, integrated construction techniques are introduced which reduce the number of separate parts and the complexity of hand assembly which is required in the 1971 Optacon. A different organization of the electrical system of the Optacon is projected in which only two kinds of integrated circuit chips (both custom chips) will be required for projected Optacons.

2) A Projected One-Hand Optacon Will Be Simpler to Use - Improved Performance Is Expected

The use of a new class of complementary MOS integrated circuits is planned which will reduce significantly the size and power

requirements of the Optacon. CMOS IC's and integrated construction of the tactile screen in a new organization make a self-contained device of the size and shape indicated in Figures 11 and 12 possible.

Reading performance with the one-hand Optacon is anticipated to be facilitated. In the first place, only one hand is required of the reader, leaving the second hand free for other functions. In addition, the simultaneous use of the same hand for tactile sensations and for the guiding of the reading aid, which gives collateral information to the reading task, is anticipated to be beneficial. The degree of improvement can not be estimated without trials.

3) Psychophysical Experiments of Tactual Reading Will Guide Design Changes

A significant part of the one-hand Optacon program will be devoted to psychophysical experiments to illuminate the nature of tactual reading. With more sophisticated instruments than were heretofore possible, explicit results are anticipated indicating the nature of and physical limitations attendant to the reading task. This information will be applied in the design of subsequent versions of the tactile screen and other Optacon parts.

Observations

A. Technology Can Ameliorate the Problem of Blindness

1) Usefulness of the Optacon Demonstrates the Point

The 1971 Optacon was realizable because custom integrated circuits were made which could be used in its miniature camera and in the electronic circuits required to drive the tactile screen. Piezoelectric devices used in the tactile screen constitute a second component of contemporary technology which made the present Optacon possible. Thus technology not available a decade ago enabled the development of the 1971 Optacon and its current production. The degree to which current users of the Optacon have benefited from their use of the device in their personal reading verifies that this application of technology has in fact ameliorated the condition of their blindness.

2) High Level Research Is Required to Apply Technology to Blindness

The development of the present Optacon is only possible in a comprehensive laboratory in which able facilities and outstanding people are together. The Office of Education project has supported the necessary collateral work in semiconductor

technology, and through its support a comprehensive capability has developed. Doctoral students, extending the underlying foundations of semiconductor engineering and inventing new devices and combinations, have produced the results thus far obtained. The Office of Education is the first government agency in the education and welfare sector which has made an investment in advanced technology to produce developments not directly obtainable as fallout from earlier defense or space research. It is only through such support that productive projects of the nature of the one described here can be carried out.

B. Government, University and Industry Are Symbiotic in Attacking Blindness With Technology

1) The University Is An Attractive Environment to Attack Blindness With Electronic Technology

A graduate electrical engineering department emphasizing doctoral research has simultaneously the technological emphasis and the expert manpower in the faculty and doctoral candidates required to apply advanced technology in new problem areas. Moreover, this environment with its simultaneous production of new instruments and the underlying research of doctoral students provides a particularly advantageous interplay between the functions of doctoral education and technological development. In particular the reading problem of blindness can be effectively attacked with technology only through advanced instruments requiring elaborate facilities and personnel with a high degree of preparation. Such a capability is only found in industrial laboratories typically committed to commercial projects of economic promise and in a very small number of graduate engineering schools. The Optacon project at Stanford offered a challenge to the faculty and doctoral students who through it have developed the most able IC activity in any university.

2) The Optacon Project at Stanford Generated Important Industrial Liaison

The environment of the engineering school with its open liaison with technical industry provides a fertile ground in which to plant an activity directing advanced technology to a human problem. The leaders of the semiconductor industry, many of whom are in this geographical area, were aware of our work at every step. In particular, the Fairchild R&D Laboratory provided important counsel at the outset of our development of a working silicon retina. Continuing liaison with the semiconductor industry has been crucial.

The Ph.D.'s produced, a co-product of the Stanford Optacon project, are of great interest as employees of the semiconductor industry. Our technical progress, reported at the foremost professional meetings and in the corresponding journals, gave prominence to the technical advances and to the application of this advanced technology to the problem of blindness.

3) University Openness Stimulates Broad Application

Federal support of an R&D effort in an open university with broad publication and interaction stimulates wide use of the results provided. An instance of follow-on research is that the visual substitution system of Drs. Bach-y-Rita and Collins. Dr. Collins' work with tactual presentations was stimulated by early experiments at Stanford.

4) Government Support of R&D in the University Provides Instruments to the Blindness System* at Incremental Cost

The R&D work supported by the Office of Education at Stanford University made it possible for Telesensory Systems to be established to produce and sell Optacons. Moreover, because of the work done at Stanford University the selling price of the Optacon is based on the incremental cost independent of the research and development cost which had preceded it. The lack of the requirement to recoup research and development expenses in the sale price of Optacons means that Optacons can be distributed to the blindness system at their incremental cost.

5) Government Development of Reading Aids Constitutes an Investment in Human Capital

Improved access to the reading materials of the sighted constitutes an important personal advantage to the blind individually. But more than that, it constitutes an important capability which makes the blind employable in the work of the sighted world. The payoff to the government is complete when the blind are able, through their increased capabilities, to be productive in the economic society in which they participate. Thus the investment of the government in reading aids for the blind is an investment in human capital made more productive by the instruments provided.

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* Donald Schon in "The Blindness System," The Public Interest, No. 18, Winter 1970, pp. 25-38, identifies the blindness system as the combination of the blind with organizations that serve them and provide their needs in rehabilitation and education. This "system" comprises a gross effort of half a billion dollars per year.

6) Openness of TSI to Competition Is Insurance to the Blindness System of Economical Instruments

The necessary and mutually desired openness of the OE-Stanford-TSI relationship implicitly provides insurance to the blindness system and to the public that good value will be received for its financial support. The only insurance the commercial enterprise, TSI, has against competition is its own effectiveness. When other enterprises find manufacture and distribution in competition attractive, they are free to enter competition for the government market. At the same time, in the best sense of American free enterprise, TSI can reward employees, managers and engineers for their effective contributions. The whole system benefits as these components of development, production and distribution are provided suitable incentive.

Recommendations

A. Disseminate 1971 Optacon

The use of the 1971 Optacon (R-1 as it is designated by TSI) provides an opportunity for the educational system to begin a new kind of training of blind students. Collateral use of the Optacon with the established other materials for blind education, primarily Braille and recordings, is a desirable evolutionary step. While the principal investigator and his colleagues believe that improved Optacons will result from added R&D at Stanford, we believe that the present Optacon should be used now and that it broadens the horizon for the blind student.

The experience gained in initial dissemination of the present Optacon provides a kind of use feedback that is very important to the development and refining of new Optacons. Preliminary experience in a school situation at San Diego identified the most vulnerable parts of the present Optacon to damage through the vigorous use typical of a high school classroom.

The usefulness of the Optacon for blind computer programmers has been verified in the Rehabilitation Center in Germany. The ambitious program and the initiative of the teachers and director have provided an example which profitably could be duplicated in the United States and elsewhere.

B. Develop Improved Optacons

1) Research in Underlying Technology

Integrated circuit technology is a young field which continues to develop rapidly. Research has been proposed in complementary MOS integrated circuits which will make possible a lower power and smaller Optacon. Sensors suitable to work at low light levels and MOS IC's to provide the high voltages required in piezoelectric vibrators constitute demanding but soluble problems in the technology of integrated systems. Continued research addressed at developing instruments and determining the limits of capability of these instruments is important.

2) Psychophysical Research

The tactual reading task and the psychophysical limitations attendant to perception and recognition of tactile characters deserve considerably more study. At the present time we know that people who are able to read Braille are able typically to learn to use the Optacon. We do not fully understand the specific limitations of performance on this task. The construction of special reading instruments will be required to conduct experiments. A program directed to the detailed understanding of the psychophysical task of tactual reading is strongly recommended.

3) Apply Research to Instrument Development

The research in technology and in psychophysical factors will provide new knowledge. Provision of the knowledge is not the end in itself, but the means to the development of more usable and effective instruments. The principal investigator strongly urges the application of research in these two areas symbiotically coupled to instrument development so that a sequence of more effective Optacons can follow.

APPENDICES

I. Facilities of the Stanford Integrated Circuits Laboratory

II. List of Personnel Involved With Development and Testing of the Tactile Facsimile Reading Aid

III. A. Graduate Degrees Awarded on the Basis of Reading Aid Research at Stanford

B. Abstracts of Dissertations and Theses on Research Sponsored by Office of Education Grant OEG-0-8-071112-2995

IV. Published Papers and Reports on Blind Reading Aid and Related Integrated Circuits Research at Stanford University and the Stanford Research Institute

V. Log of Presentations, Demonstrations and News Releases

VI. Hewlett-Packard Advertisement

VII. Relationship of Telesensory Systems, Inc. to the Optacon Research Group at Stanford University

VIII. Representative Optacon Purchasers

APPENDIX I

FACILITIES OF THE STANFORD INTEGRATED CIRCUITS LABORATORY

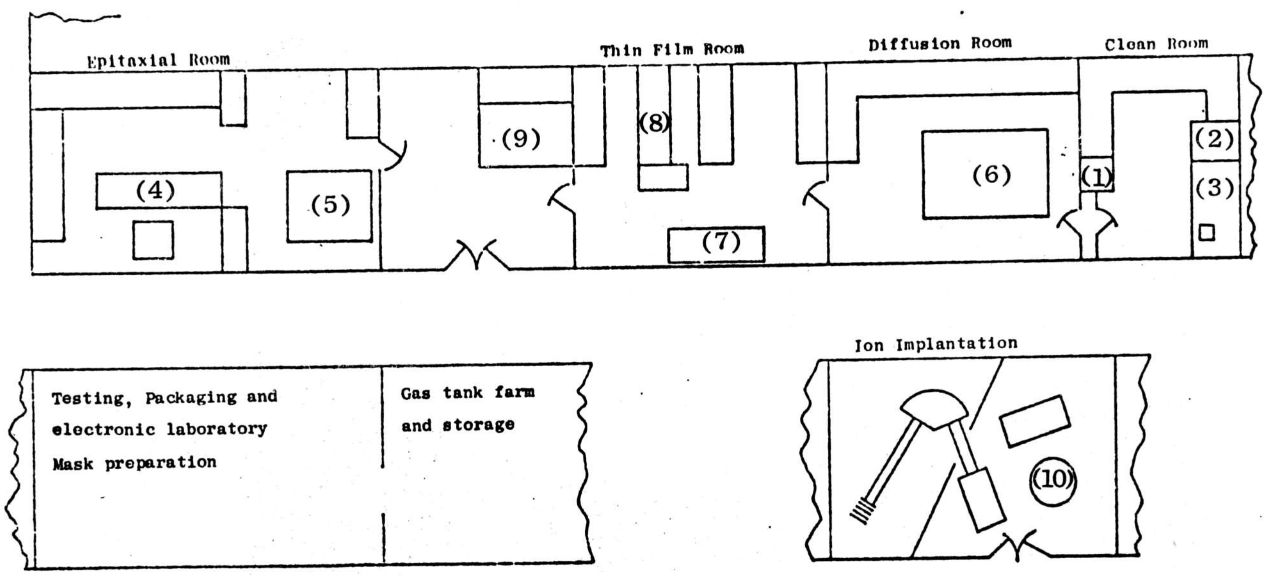
The Stanford Integrated Circuits Laboratory contains a complete facility for research, development and construction of devices and integrated circuits on silicon. A researcher here has all the necessary equipment for designing a device, making the masks, preparing and testing the silicon material, constructing the device, testing and packaging it.

The laboratory layout, shown below, covers about 3,000 sq.ft. It is divided into several areas according to type of work and degree of cleanliness needed.

The mask preparation is done on a light table, and mask manufacturing itself is performed using a reduction camera (1) in the clean room. This room also serves for photolithography (2) and mask alignment (3). The starting silicon material is tested and the initial layers are prepared in the epitaxial room (4). Two sets of diffusion furnaces (5) and (6) serve to introduce controlled amounts of impurities into the silicon material which form an additional layer composing a future circuit. Silox machine (7) and evaporators (8) serve to make insulating and conductive layers on top of the finished circuit. Another and new way of introducing the impurities into silicon is ion implantation which can be performed in a separate part of the laboratory (10).

Initial teaching of the students is done in a training laboratory (9) where some of the key facilities are duplicated. The laboratory also has a supply of pure gases, water filters, purifiers and large storage areas for chemicals, glassware, etc.

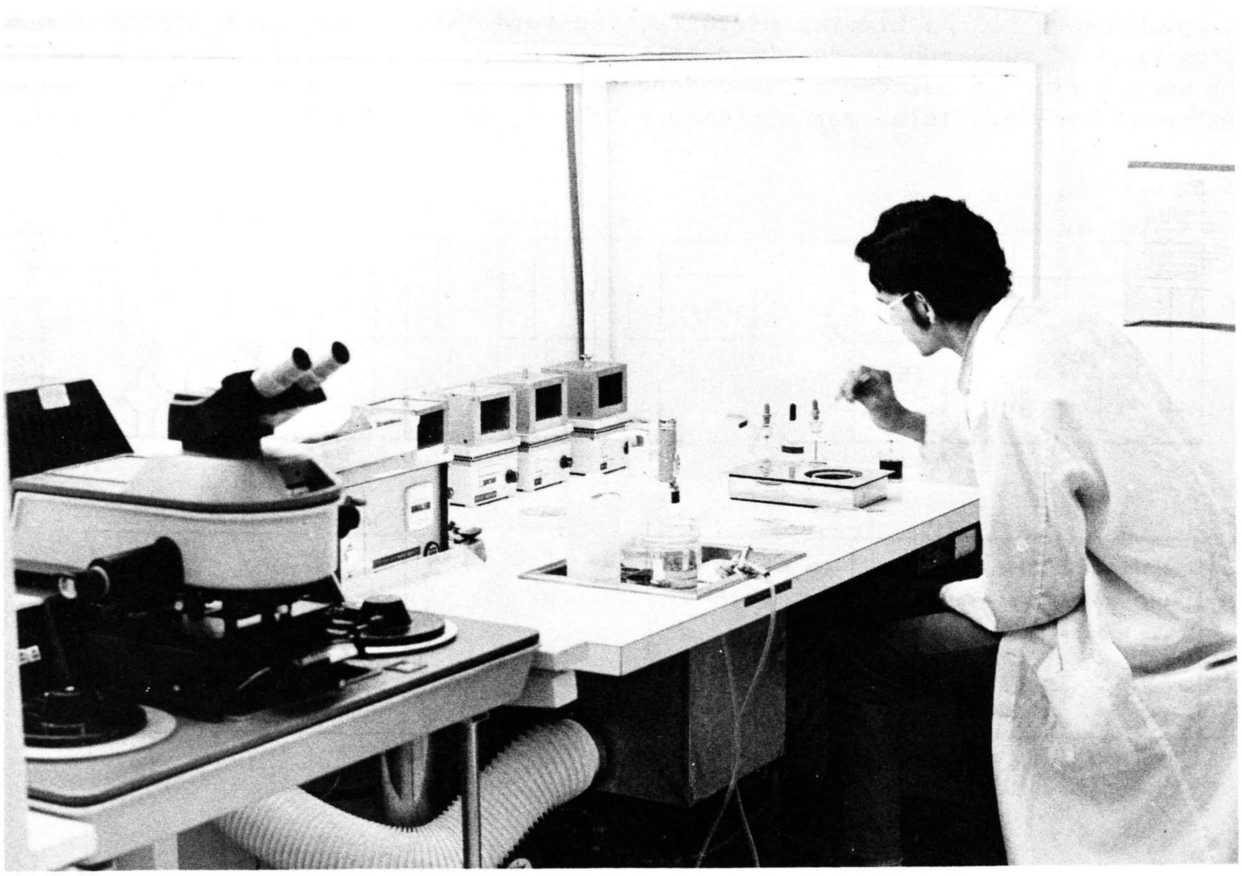
During the past five years of intensive research, the laboratory has accumulated a large amount of theoretical and practical knowledge. All the main technologies used for manufacturing integrated circuits on silicon are available here (bipolar technology with various types of isolation, aluminum gate MOS technology, complementary MOS on bipolar circuits, and recently silicon gate MOS technology). This type of research currently continues. Also, the location of the laboratory is very fortunate because a researcher can use the facilities of the Center for Material Research (electron microscopy, X-ray, diffraction) in the same building.



THE LABORATORY LAYOUT

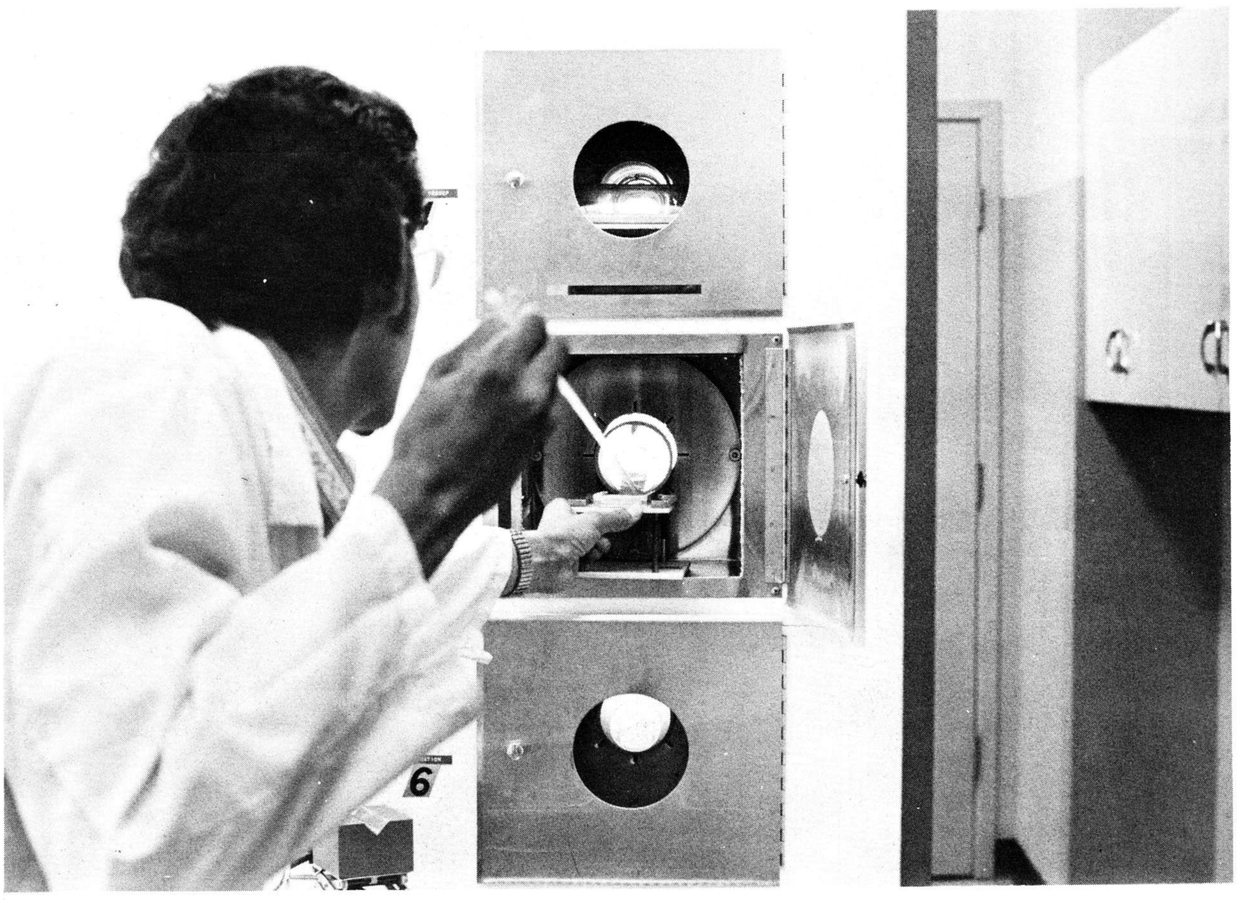
The photographs on pages 37-39 show key pieces of the laboratory equipment.

LIGHT TABLE FOR MASK PREPARATION

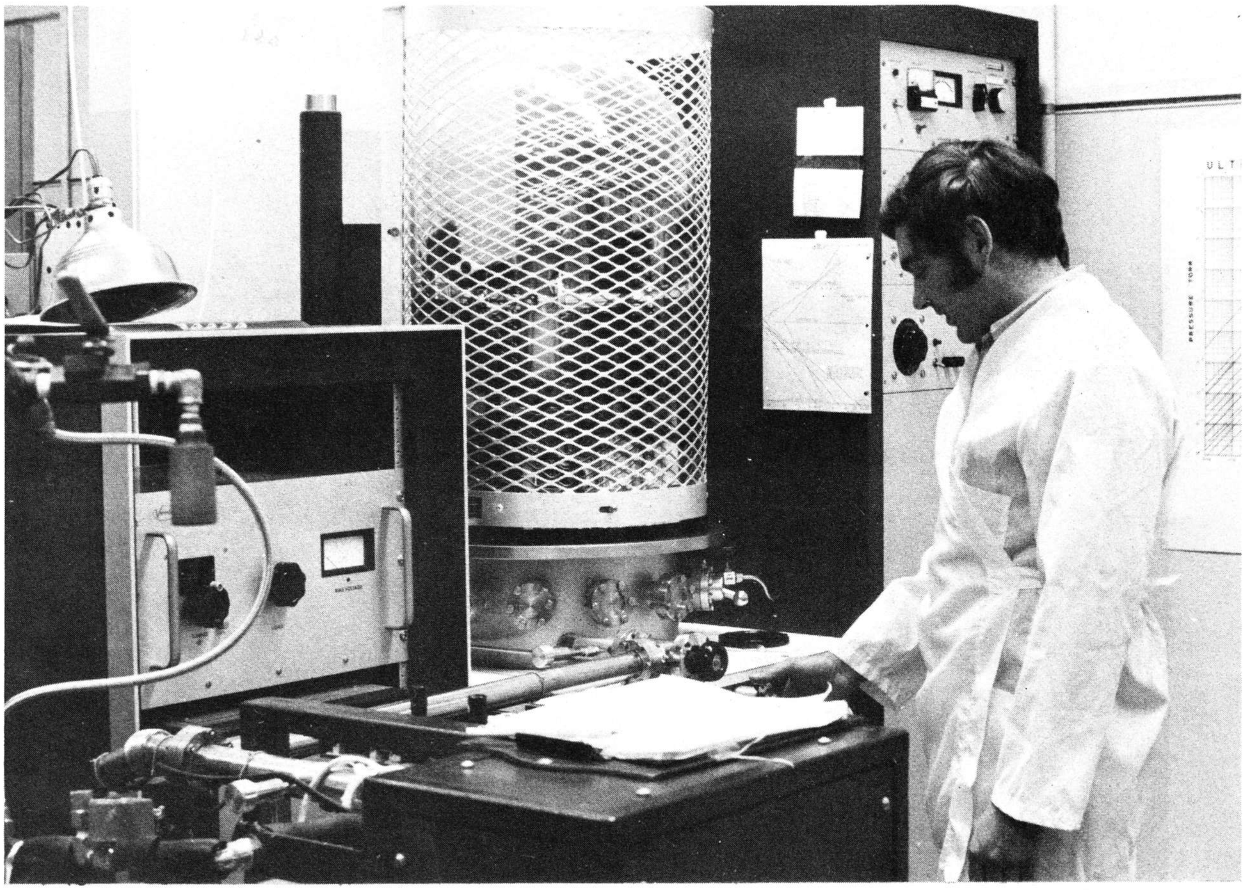


ALIGNMENT AND PHOTOLITHOGRAPHY BENCH

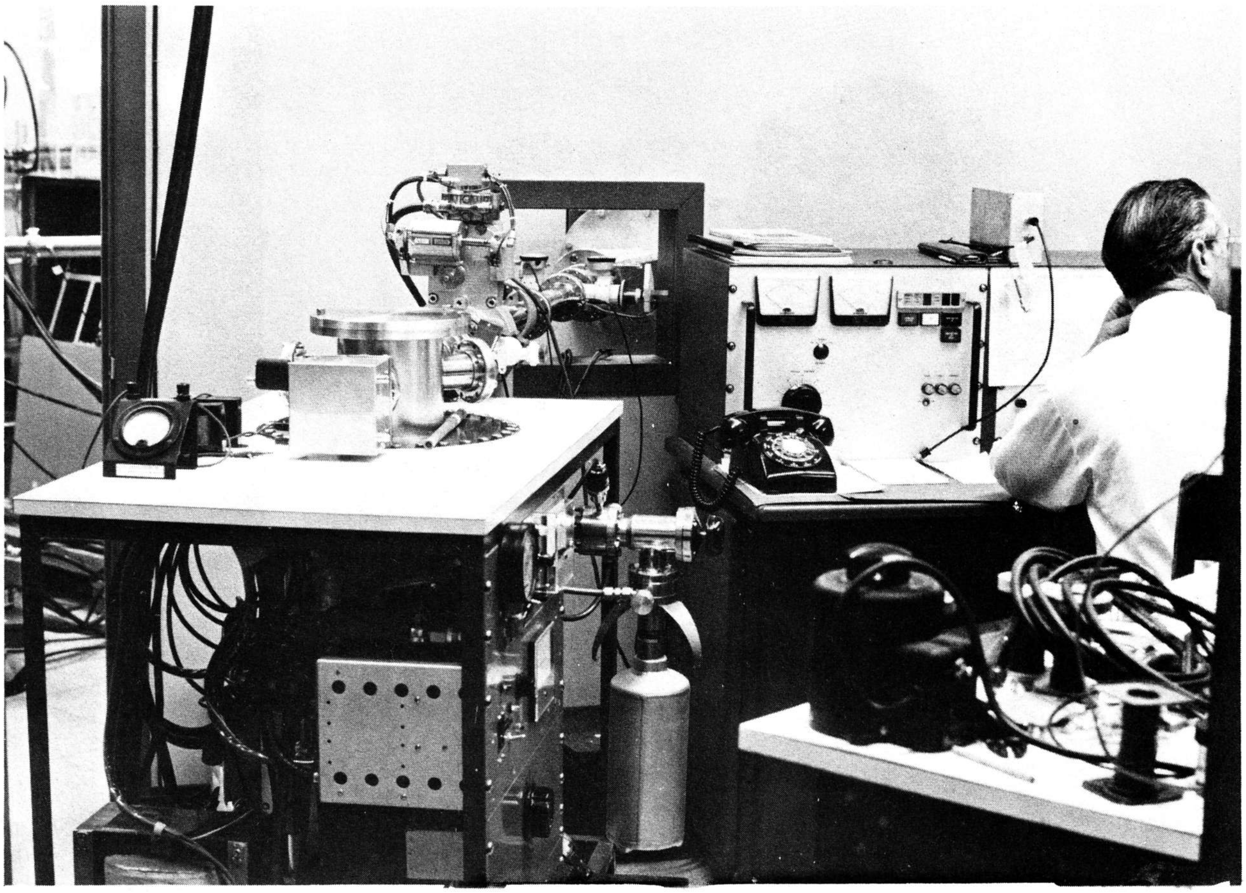
EPITAXIAL MACHINE



DIFFUSION FURNACES



VACUUM EVAPORATOR AND SPUTTERING SYSTEM



ION IMPLANTATION

APPENDIX II

LIST OF PERSONNEL INVOLVED WITH DEVELOPMENT AND TESTING OF THE TACTILE FACSIMILE READING AID

Addison, Robert L., Student at California State University, Hayward, and blind experimenter 1968-1970

Alonzo, Gerald J., Graduate student, Stanford EE 1961-1964; research assistant SEL, awarded Engineer degree 1964

Andres, Kent W., Graduate student, Stanford EE 1966-1968, NSF Fellow, awarded Engineer degree 1969

Baer, James A., Senior Research Engineer, Information Science and Engineering Science Division, Stanford Research Institute

Bandy, Steve G., Graduate student, Stanford EE 1965-1969, NSF Fellow, awarded Ph.D. degree 1970

Barry, Agnes, Administrative assistant, Optacon project, 1971-1972

Beaudouin, Jacques, Senior Semiconductor Engineer, Integrated Circuits Laboratory, SEL, 1968-present

Bennett, Ian, Graduate student, Stanford EE 1968-present, research assistant SEL

Berger, Josef, Research Associate (from Czechoslovakia), SEL, 1968-1972

Berkheiser, Herschell, Electronics Technician, SEL, 1970-present

Bertora, Franco, Visiting Research Associate (from University of Genoa), SEL, 1969-1970

Bigelow, David, Graduate student, Stanford EE 1967-1971, research assistant SEL, awarded Ph.D. degree 1973

Blanchard, Richard, Graduate student, Stanford EE 1970-present, research assistant SEL

Bliss, James D., Associate Professor of Electrical Engineering, Stanford, and Head, Bio-information Systems Group, SRI, until 1971; since 1971 President, Telesensory Systems, Inc., and Senior Research Associate, SEL

Brugler, J. Stephen, Research Associate SEL 1968-1973; since 1971 Vice-President, Telesensory Systems, Inc.

Calfee, Robert C., Professor of Education, Stanford

Chiabrera, Alessandro, Research assistant (Volta Fellow), SEL, 1968

de Purcel, Antonio, Graduate student, Stanford School of Education, awarded M.S. 1971, Research assistant SEL 1971

Fajardo, Jane E., Administrative assistant, Optacon project, 1972-present

Frankfurt, Carroll, Electronics Technician, SEL, 1947-present

Fuchs, Henry O., Professor of Mechanical Engineering (Design Division), Stanford

Gardiner, Kenneth, Senior Research Engineer, Information and Control Group, Stanford Research Institute

Garland, Harry T., Research Associate, SEL, 1972-present

Gary, Paul A., Graduate student, Stanford EE 1962-1967, research assistant SEL, awarded Ph.D. degree 1967

Gheewala, Tushar, Graduate student, Stanford EE 1971-present, research assistant SEL

Hill, John W., Research Engineer, Information Science and Engineering Division, Stanford Research Institute; graduate student, Stanford EE 1963-1967, awarded Ph.D. degree 1967

Horiuchi, Shigeharu, Visiting Research Associate (from Japan), SEL, 1970-1972

Jerabek, Paul, Electronics Technician, SEL, 1972-present

Jespers, Paul, Visiting Professor of Electrical Engineering (from University of Louvain, Belgium), Stanford, 1968-1969

Joy, Richard C., Graduate student, Stanford EE 1964-1968, research assistant SEL, awarded Ph.D. degree 1968

Joy, Richard, Deaf-blind experimenter, 1970 (not Dr. Joy, above)

Landsman, Howard A., Graduate student, Stanford EE 1967-1971, research assistant SEL, awarded Engineer degree 1971

Linvill, Candy, Student at Stanford 1969-present and blind experimenter 1964-present

Linvill, John G., Professor and Chairman, Department of Electrical Engineering, Stanford

Mackworth, Norman H., Research Associate, Department of Psychology, Stanford

Maginness, Maxwell G., Research Associate (from New Zealand), SEL, 1971-present

May, Gerald, Graduate student, Stanford EE 1971-present, research assistant SEL

McBride, Laurence C., Graduate student, Stanford EE 1967-1971, NSF Fellow and research assistant SEL, awarded Ph.D. degree 1971

Meindl, James D., Professor of Electrical Engineering, Stanford; Director, SEL

Meisenbach, Lewis S. II, Electronics Technician, SEL, 1970-present

Melen, Roger D., Graduate student, Stanford EE 1968-1972, research assistant SEL, awarded Ph.D. degree 1973; Research Associate, SEL, 1972-present

Melrose-Voorhees, Susan, Student at Stanford and blind experimenter 1968-present

Nordstrom, Robert A., Graduate student, Stanford EE 1966-1971, research assistant SEL, awarded Ph.D. degree 1971

Norris, Zora, Solid State Technician, SEL, 1969-present

Plummer, James, Graduate student, Stanford EE 1966-1971, research assistant SEL, awarded Ph.D. degree 1971, Research Associate, SEL, 1971-present

Pomroy, Ervin L., Senior Electronics Technician, SEL, 1963-1972

Proscia, Vito, Blind experimenter, Vice-President for Sensory Aid Programs, Telesensory Systems, Inc.

Reynolds, Tracy, Junior high school student and blind experimenter 1969-1971

Rogers, Charles H., Graduate student, Stanford EE 1966-1970, NSF Fellow, awarded Ph.D. degree 1970

Ruegg, Heinz W., Graduate student, Stanford EE 1963-1966, research assistant SEL, awarded Ph.D. degree 1966

Salsbury, Phillip, Graduate student, Stanford EE 1964-1969, NSF Fellow and research assistant SEL, awarded Ph.D. degree 1969; Research Associate, SEL, 1969-1970

Sandberg, Chester, Graduate student, Stanford ME 1970-1971, research assistant SEL, awarded M.S. degree 1972

Saraswat, Krishna, Graduate student, Stanford EE 1968-present, research assistant SEL

Schick, John F., Machine Shop Foreman, SEL, 1951-1973

Schoof, Loren II, Blind experimenter 1965-present, student at Stanford 1968-1971, awarded M.S. in Operations Research 1971; Research Associate, SEL, 1971-present

Schreiner, Henry, Blind experimenter and student at Stanford Summer 1971

Shepard, Raymond P., Graduate student, Stanford School of Education 1968-1970; Research Associate, Bio-information Systems Group, Stanford Research Institute 1968-1970

Stearns, Robert, Blind experimenter and Computer Programmer, Stanford Research Institute

Taenzer, Jon C., Graduate student, Stanford EE 1964-1971, research assistant SEL, awarded Ph.D. degree 1971; Research Associate, Bio-information Systems Group, Stanford Research Institute, 1969-1971, Research Engineer 1971-present

Taperell, Ronald E., Senior Semiconductor Technician, SEL, 1958-present

Wang, Chi-Shin, Graduate student, Stanford EE 1970-present, research assistant SEL

Watney, John, Graduate student, Stanford EE 1965-present, research assistant SEL

Weihl, Carolyn, Research Associate, Information Science and Engineering Division, Stanford Research Institute 1967-1972; since 1972 Training Manager, Telesensory Systems, Inc.

Wise, Jo Anne (Clayton), Administrative assistant, Optacon project, 1968-1971

Wu, Tao-Yuan, Graduate student, Stanford EE 1967-1971, research assistant SEL, awarded Ph.D. degree 1971

Young, William T., Electronics Technician, SEL, 1958-1972; since 1972 Senior Engineer, Telesensory Systems, Inc.

APPENDIX III

GRADUATE DEGREES AWARDED ON THE BASIS OF READING AID RESEARCH AT STANFORD

Year	Degree	Student	Dissertation/Thesis Title	Report No. [Sponsor]
1964	E.E.	Gerald J. Alonzo	Development of a Piezoelectric Dynamic Embosser for Use as a Reading Machine	TR 4813-4 [ONR]
1966	Ph.D.	Heinz W. Ruegg	Avalanche Multiplication as a Gain Mechanism in Photodiodes	TR 4820-2 [ONR]
1967	Ph.D.	Paul A. Gary	Modeling and Optimization of a Silicon Photosensor for a Reading Aid	TR 4822-1 [ONR]
1967	Ph.D.	John W. Hill	The Perception of Multiple Tactile Stimuli	TR 4823-1 [NIH]
1968	Ph.D.	J. Stephen Brugler	Low-Light-Level Limitations of Silicon Junction Photodetectors	TR 4824-1 [JSEP]
1968	Ph.D.	Richard C. Joy	Charge Storage Mode Operation of Phototransistors in a Reading Aid	TR 4825-1 [ONR]
1968	E.E.	Kent W. Andres	A Simple Characterization of Gate-to-Substrate Impedance in Metal-Oxide-Semiconductor Structures under Nonequilibrium Conditions	TR 4825-2 [ONR]
1969	Ph.D.	Phillip J. Salsbury	A Monolithic Image Sensor for a Reading Aid for the Blind	TR 4828-1 [OE]
1969	Ph.D.	Steve G. Bandy	Design, Fabrication, and Evaluation of a Silicon Junction Field-Effect Photodetector	TR 4828-2 [OE]
1970	Ph.D.	Charles H. Rogers	The Importance of Vibration Frequency in Tactile Pattern Perception	TR (SRI) [NINDS]
1970	M.A.*	Raymond P. Shepard	Information in Handling Acoustic and Tactile Short-Term Memory	[NIH]
1971	E.E.	Howard A. Landsman	The Measurement of Spectral Responsivity for Silicon Photodevices	TR 4828-3 [OE]
1971	Ph.D.	Jon C. Taenzer	Some Psychophysical Limitations on Reading Performance	TR 4828-4 [OE]
1971	Ph.D.	Robert A. Nordstrom	The Field-Effect Modified Transistor: A New Integrated Circuit Device	TR 4828-5 [OE]
1971	Ph.D.	James D. Plummer	MOS Electronics for a Reading Aid for the Blind	TR 4828-6 [OE]
1972	Ph.D.	David W. Bigelow	MOS Analog Shift Register Image Sensor	TR 4829-1 [JSEP]
1972	Ph.D.	Roger D. Melen	CCD Image Sensors for a Reading Aid for the Blind	TR 4828-7 [OE]

* School of Education, San Francisco State College

The pages immediately following are abstracts of the dissertations and thesis emanating from work sponsored by Office of Education Grant OEG 0-8-071112-2995.

B. ABSTRACTS OF DISSERTATIONS AND THESES ON RESEARCH SPONSORED BY OFFICE OF EDUCATION GRANT OEG-0-8-071112-2995

A MONOLITHIC IMAGE SENSOR FOR A READING AID FOR THE BLIND

Phillip J. Salsbury, Ph.D.
Stanford University, 1969

A novel optical-tactile reading aid giving a blind person immediate access to virtually all printed material used by sighted people has been developed, which occupies a volume approximately equal to that of an ordinary desk-size dictionary. A singular feature of this instrument is a silicon monolithic image-sensing array that serves as the "retina" of the reading aid. Signals from the retina are used to control an array of piezoelectric stimulators that form tactile images of printed characters.

The image sensor consists of a 144-element matrix of bipolar phototransistors integrated on a silicon chip approximately 2×4 mm in size and is designed on the basis of electrical, optical, psychological, and psychophysical considerations. The order (24×6) and aspect ratio (2:1) of the array are determined by the resolution and field-of-view requirements of the reading aid, which in turn depend on printed-character dimensions, short-term human memory, tactile-stimulator size, and index-finger dimensions. A column-isolated structure maximizes the active photosensing area, and a one-dimensional scanning technique minimizes spurious outputs and reduces the complexity of the total system.

The individual photosensing elements are optimized for maximum responsibity, uniformity, and dynamic range. Array cell area ($\sim 125 \times 250\ \mu$) represents the best compromise for high performance, small reading head size, and high fabrication yields. The junction depths and resistivities of the monolithic structure are based on the desired spectral response and on electrical constraints derived from a detailed analysis of array operation during a complete frame period. Output nonuniformity is minimized and harmful intercellular crosstalk is virtually eliminated by designing for phototransistor $h_{FE} \geq 200$ and $C_{TC}/C_{TE} \geq 5$. Maximum visible and minimum infrared spectral response is achieved by optimizing SiO_2 thickness (~6600 A), base-collector junction depth (~2 μ), and collector-substrate junction depth (~12 μ).

Measured performance of the array correlates well with the predicted characteristics. Typical output nonuniformity at 1 V is ±6 percent, with no evidence of electrical or optical crosstalk.

Abstract TR 4828-1

DESIGN, FABRICATION, AND EVALUATION OF A SILICON JUNCTION FIELD-EFFECT PHOTODETECTOR

Steve Gary Bandy, Ph.D.
Stanford University, 1970

A new device for photodetection is introduced in this study which is capable of responsivities comparable to devices operating in the charge-storage mode. Since the physical process involved corresponds to a photodiode in series with a high value of resistance, the device operates in real time and hence avoids the problems of switching encountered in the charge-storage mode at low-light levels. The device utilizes this physical process in a new technique which significantly reduces the required surface area.

Although the junction field-effect transistor serves as the prototype for the device, considerations for improving the magnitude of the output response and its linearity along with the gain-bandwidth product lead to a device having a very low transconductance g_m and a large cutoff voltage V_{GC}. An analysis is performed to determine the relationships between the device parameters and the goal of maximizing the linearity of the output voltage to the photocurrent. This analysis is also applicable to the problem of achieving large values of signal insensitive resistance for use in integrated circuit applications.

Field-effect photodetectors fabricated in the Stanford Integrated Circuits Laboratory in accordance with the principles developed for optimum photodetection are evaluated. Epitaxial silicon of conventional doping was used in the fabrication. The devices are found to exhibit the photodetecting characteristics expected from theoretical considerations. A simple two-lump approximation of the distributed gate-channel interface is found to adequately describe the frequency response of the devices.

In contrast to the area-independent responsivity of the charge-storage mode, it is shown that the responsivity of the field-effect photodetector is proportional to the square of the device surface area. Depending upon the illumination level and the deviation from linearity that is tolerable, this area dependence presents one of the fundamental drawbacks of the field-effect photodetector for application in dense arrays.

THE MEASUREMENT OF SPECTRAL RESPONSIVITY
FOR SILICON PHOTODEVICES

Howard Alan Landsman, E.E.
Stanford University, 1971

The concept of photodevice spectral responsivity is described and an instrument to measure this property is presented. The need for this measurement arises from the operation of a silicon phototransistor array used for image sensing in a reading aid for the blind. The contrast of printed material is a maximum for greenish-yellow light, the same wavelength region as the maximum sensitivity of the human eye. It therefore is necessary to use a sensor which responds to radiation of the same wavelength. Silicon photosensing diodes can be designed to operate in this region, a process which has been achieved for the bipolar phototransistor array.

The design of an instrument for response measurements requires specification of an optical radiation source, response monitor and housing. The principal element in the system is the radiation source which must be stabilized and characterized. A continuous spectrum source and set of optical interference filters are employed to obtain nearly monochromatic radiation at ten wavelengths.

The measurement of spectral responsivity for a group of silicon photodevices is presented. These measured results are compared with those predicted by one dimensional models proposed by several investigators in the field. The results are used to compute total response of a diode to a tungsten light bulb.

Abstract TR 4828-3

SOME PSYCHOPHYSICAL LIMITATIONS ON READING PERFORMANCE

Jon C. Taenzer, Ph.D.
Stanford University, 1971

A group of experiments on visual and tactile reading have been performed. The visual experiments used a 12 × 12 element display of lettershapes arranged in English text moving from right to left across the array in a New York Times-Square-News-Display fashion. As both speed of presentation and the width of the display were varied, it was found that a constant 150 ms display time was necessary for the subjects (who were reading aloud) to read with 95% word accuracy. This point is taken as the 100% comprehension level. For this level of performance, the display speed was found to be directly proportional to the window width. Zero percent word accuracy occurred for display times of 50 ms or less. This 50 ms processing delay, or dead time, may be due to visual system limitations rather than central processing system limitations.

A low-horizontal-resolution experiment showed that at slow display speeds, a reduction in resolution also reduces accuracy, while at speeds above approximately 5.0 letterspaces/sec, an increase in accuracy can be achieved by spreading the same number of display columns over a wider field of view. However, it is only possible to realize a 25% improvement in this way. Reading accuracy was also increased by masking the display on either side with light areas. This result supports the ideas that eye movement is an integral part of reading this constant-rate display, and that the resulting erasure before and after presentation of the information must reduce the confusion of preceding and following material and/or extraneous visual noise.

Tactile reading of a constant-rate display, as well as tactile reading with no speed restrictions (by using an Optacon) showed that, for small window widths, restricted-speed reading is slower than free-rate reading. In addition, it was found that, because of the added tracking task, reading speed is not directly proportional to window width. This agrees with the theory presented. A word-by-word analysis of the constant-display-speed data shows that for any specific display speed, accuracy of detection appears to be a logarithmic function of word length. An analysis of the free-reading data shows that reading with 100% comprehension involves scanning all words with approximately the same average time-per-letterspace. In addition, a probability modeling exercise indicates that the neural processing mechanism is time-shared between different functions (such as information processing and manual tracking) and is cyclic with a period of about 90 ms, i.e. if information is not fully processed in the first 90 ms cycle, then one or more additional processing cycles are used. It appears that during these processing cycles no new information is accepted. This model of the neural processing system is capable of predicting the results which were measured during both the tactile and visual experiments.

Abstract TR 4828-4

THE FIELD-EFFECT MODIFIED TRANSISTOR:
A NEW INTEGRATED CIRCUIT DEVICE

Robert A. Nordstrom, Ph.D.
Stanford University, 1971

A new integrated circuit device which can be described as a field-effect modified (FEM) bipolar transistor has been developed. The distinguishing feature of this compound transistor structure is a diffused annular gate region around the emitter. No additional processing steps are required to fabricate FEM transistors since the gate is formed during the emitter diffusion. The gate, which is connected to the collector, divides the base into an internal base region, containing the emitter, and an external base region. When the collector and gate junctions are sufficiently reverse biased, the region under the gate becomes depleted and the channel connecting the two portions of the divided base is pinched-off. The capability of pinching-off this channel is of fundamental importance to the operation of the FEM transistor.

An FEM phototransistor operating in the charge-storage mode can have an order of magnitude higher responsivity than a comparable conventional phototransistor. The photocurrent of the FEM transistor includes both the internal and external base photocurrents, whereas the effective collector-base capacitance is that of the internal base region only. The resulting higher responsivity is important for operation at low light levels. Other applications of the FEM transistor include a high noise-immunity inverter for digital circuits, a simple semiconductor memory element, a voltage threshold detector circuit, and a light intensity-to-pulse repetition rate converter.

Theory necessary to explain and predict the characteristics and behavior of FEM transistors is developed in this report. This theory is supported by experimental results obtained from measurements made on FEM transistors fabricated in the Stanford University Integrated Circuits Laboratory. The charge-storage mode of operation for FEM transistors is analyzed and the increased responsivity is explained. Upper limits on FEM transistor performance are established. Other applications which utilize the unique characteristics of the FEM transistor are also described.

Abstract TR 4828-5

MOS ELECTRONICS FOR A READING AID FOR THE BLIND

James D. Plummer, Ph.D.
Stanford University, 1971

A unique direct translation reading aid for the blind, the Optacon, has been developed using monolithic silicon integrated circuit technology. This instrument allows the blind direct access to the reading materials of the sighted, such as books and newspapers. Blind subjects have achieved reading rates greater than 80 words per minute, indicating that the Optacon will become widely used by the blind.

The Optacon consists of a monolithic array of 144 phototransistors which act as a retina and integrated electronics, which use the light/dark information from the retina to control a corresponding 144 element array of piezoelectric tactile stimulators or bimorphs. Small size and weight and low cost are clearly desirable features of this system in order to enhance portability and increase availability. These goals are met through the use of two custom MOS integrated circuits, which represent essentially complete integration of the Optacon system. The first MOS integrated circuit is a self-scanned image sensing array. The second is a digital MOS circuit which decodes the information from the retina and controls the tactile stimulators directly.

A detailed analysis of the behavior of MOS phototransistors operating in the charge storage mode has led to an understanding of the device parameters which limit performance in this application. Experimental measurements on single devices and integrated phototransistor arrays fabricated in the Stanford Integrated Circuits Laboratory have confirmed the theoretical results. It is shown that switching noise generated during the scanning of the array, is the limiting factor in determining the minimum light levels integrated MOS phototransistors can reliably detect, if nothing is done to eliminate these transients. Through the results of the analysis, however, a design is evolved for a self-scanned MOS image sensing array which has virtually zero switching noise present at its output. Such an array has been fabricated and it is shown experimentally to be limited in the light levels it can detect only by the thermal leakage currents of the phototransistors. This type of array will greatly improve the performance of the Optacon system and has potential for wide use in other low light level image sensing applications as well.

The unique requirements placed on the second custom MOS integrated circuit by the tactile stimulators it drives present several unusual problems. In particular, the breakdown voltage of the output driver transistors is required to be a minimum of 60 volts. In addition, because of the highly capacitive load which the bimorphs present to the integrated circuit, the current gain of parasitic lateral PNP bipolar transistors on the MOS chip must be minimized.

CCD IMAGE SENSORS FOR A READING AID FOR THE BLIND

Roger Douglas Melen, Ph.D.
Stanford University, 1972

Charge coupled devices (CCD's) are recently-discovered semiconductor realizations of analog shift registers that have many potential advantages compared with other devices capable of electronic scanning and delay. These new devices are basically linear arrays of closely-spaced MOS capacitors.

A detailed investigation of the performance of CCD's for application in the Optacon, a new reading aid for the blind, is described in this report. The performance of the CCD shift register scanning circuitry and the transparent electrode structure used to realize a new type of image sensor are analyzed.

A simple model of the semiconductor surface is used to determine the effects of minority carrier trapping on the analog shift register performance. These trapping effects are important to the operation of the image sensor because they produce delayed charge in its output signal. The model of the surface which is used separates the effects at the surface into two classes: those associated with traps in the forbidden gap of the semiconductor at the surface, and those associated with traps in the oxide near the surface of the semiconductor. While other investigators have shown drift and diffusion to limit transfer efficiency at high clock frequencies (frequencies greater than 10^5 Hz are representative of typical values), in this work the traps in the forbidden gap are shown to limit the transfer efficiency at medium clock frequencies (10^4 Hz) and the traps in the oxide are shown to limit transfer efficiency only at low clock frequencies (less than 10^3 Hz).

A simple noise model for a practical CCD image sensor is presented. Capacitively coupled, as well as transfer and leakage current noises are considered. An amplifier, fabricated on the same semiconductor substrate as the CCD, is presented as a technique to reduce capacitively coupled noises at medium clock frequencies.

Transparent polycrystalline silicon capacitor electrodes are presented as the basis of a front-side illuminated CCD image sensor. The influence of this transparent electrode structure on the spectral response of the image sensor is analyzed. Reflection of light from the polycrystalline silicon layer is found to be the most significant factor in the performance of the structure.

An 8 × 3 CCD area image sensing array, built in the Stanford Integrated Circuits Laboratory, is evaluated with regard to the Optacon. It is concluded that CCD's are useful as image sensors in this application particularly for large, high density arrays.

Abstract TR 4828-7

APPENDIX IV

PUBLISHED PAPERS AND REPORTS
ON BLIND READING AID AND RELATED INTEGRATED CIRCUITS RESEARCH
AT STANFORD UNIVERSITY AND THE STANFORD RESEARCH INSTITUTE

1. K. Kotovsky and J.C. Bliss, "Tactile Presentation of Visual Information," Trans. IRE, Vol. MIL-7, Nos. 2 & 3, pp. 108-113, April-July, 1963.

2. G.J. Alonzo, "Development of Piezoelectric Dynamic Embosser for Use as a Reading Machine," Rept. SEL-64-021, TR No. 4813-4, Stanford Electronics Laboratories, Stanford, Calif., March 1964. (Engineer's Thesis)

3. J.C. Bliss and H.D. Crane, "A Computer-Aided Instrumentation System for Studies in Tactual Perception," Proc. of the 1964 National Aeronautical Electronics Conference, Dayton, Ohio, May 1964, pp. 375-384.

4. J.C. Bliss and H.D. Crane, "Experiments in Tactual Perception," Final Report, Contract NAS 2-1679, SRI Project 4656, Stanford Research Institute, Menlo Park, Calif., January 1965.

5. J.G. Linvill and J.C. Bliss, "A Direct Translation Reading Aid for the Blind," Rept. SEL-65-055, TR No. 4819-1, Stanford Electronics Laboratories, Stanford, Calif., May 1965.

6. J.C. Bliss, H.D. Crane and S.W. Link, "Tactual Perception: Experiments and Models," Interim Report, Contracts NAS 2-2752 and AF33(615)-1099, SRI Projects 5438 and 4719, Stanford Research Institute, Menlo Park, Calif., June 1965.

7. J.C. Bliss, "Sensory Aids for the Blind," McGraw-Hill Yearbook Science and Technology, 1966, pp. 357-360.

8. J.G. Linvill and J.C. Bliss, A Direct Translation Reading Aid for the Blind," Proc. IEEE, Vol. 54, pp. 40-51, January 1966.

9. H.W. Ruegg, "Avalanche Multiplication as a Gain Mechanism in Photodiodes," Rept. SEL-66-008, TR No. 4820-2, Stanford Electronics Laboratories, Stanford, Calif., March 1966. (Ph.D. Dissertation)

10. J.C. Bliss, H.D. Crane, S.W. Link and J.T. Townsend, "Tactile Perception of Sequentially Presented Spatial Patterns," Perception and Psychophysics, Vol. 1, pp. 125-130, May 1966.

11. J.C. Bliss, "Tactual Perception: Experiments and Models," Final Report, Contracts NAS 2-2752 and AF33(615)-1099, SRI Projects 5438 and 4719, Stanford Research Institute, Menlo Park, Calif., May 1966.

12. J.C. Bliss, H.D. Crane and S.W. Link, "Effect of Display Movement on Tactile Pattern Perception," Perception and Psychophysics, Vol. 1, pp. 195-202, June 1966.

13. H.D. Crane and S.W. Link, "Exploratory Experiments on Tactile-Spatial Interactions," in J.C. Bliss, "Tactual Perception: Experiments and Models," TR-AFAL-TR-66-242, Air Force Avionics Lab., Wright-Patterson Air Force Base, Ohio, July 1966.

14. J.C. Bliss, H.D. Crane, P.K. Mansfield and J.T. Townsend, "Information Available in Brief Tactile Presentations," Perception and Psychophysics, Vol. 1, pp. 273-283, August 1966.

15. J.C. Bliss and J.G. Linvill, "A Direct Translation Reading Aid," in Sensory Devices for the Blind, ed. Richard Dufton, pp. 389-407, J.W. Arrowsmith, Ltd., Bristol, 1967.

16. K.W. Gardiner and J.C. Bliss, "An Optical-to-Tactile Image Converter," in Sensory Devices for the Blind, ed. Richard Dufton, pp. 299-308, J.W. Arrowsmith, Ltd., Bristol, 1967.

17. J.C. Bliss, J.W. Hill, P.K. Mansfield and B.M. Wilber, "Tactual Perception: Experiments and Models," Quarterly Report 3, Contract NAS 2-3649, SRI Project 6070, Stanford Research Institute, Menlo Park, Calif., March 1967.

18. P.A. Gary, "Modeling and Optimization of a Silicon Photosensor for a Reading Aid," Rept. SEL-67-040, TR No. 4822-1, Stanford Electronics Laboratories, Stanford, Calif., May 1967. (Ph.D. Dissertation)

19. J.G. Linvill, "Generation of Tactile Facsimiles for Blind Reading," Proceedings, National Telemetering Conference, San Francisco, Calif., May 1967, pp. 1-4.

20. J.C. Bliss, "Tactual Perception: Experiments and Models," Final Report, Contract NAS 2-3649, SRI Project 6070, Stanford Research Institute, Menlo Park, Calif., June 1967.

21. J.C. Bliss, "Optical-to-Tactile Image Conversion Aids for the Blind," Archives of Physical Med. and Rehab., Vol. 48, pp. 352-353, July 1967.

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APPENDIX V

LOG OF PRESENTATIONS, DEMONSTRATIONS AND NEWS RELEASES

(Footnotes refer to Appendix IV)

1964

May 12	Presentation[1] by Dr. Bliss at National Aeronautical Electronics Conference, Dayton, Ohio: "A Computer-Aided Instrumentation System for Studies in Tactile Perception"
Aug. 18	Presentation by Dr. Linvill at Annual Contractors Meeting, Stanford Electronics Laboratories: "A Microelectronic Reading Aid for the Blind," including filmed demonstration by Candy Linvill
	Stanford University News Release
Aug. 31	"Additional Information on the Photomechanical Reading Aid for the Blind" written by Dr. Linvill as response to many inquiries stimulated by newspaper and periodical publicity
Sept. 10	Presentation by Dr. Linvill at International Conference on Circuits and Microwaves, Tokyo: "A Microelectronic Aid for the Blind" (including film)
Sept. 17	Stanford Research Institute Press Release

1965

Aug. 24	Presentation by Dr. Bliss at WESCON (Western Electronic Show and Convention), San Francisco, including film: "Microelectronic Reading for the Blind"
Dec. 27-29	Three showings of film, "Microelectronic Reading for the Blind," as part of Section M (Engineering) program at 132nd Annual Meeting of American Association for the Advancement of Science, Berkeley, California

1966

Jan. 27-28	Presentation by Dr. Bliss at 6th Technical Session on Reading Machines for the Blind, sponsored by Prosthetic and Sensory Aids Service, Veterans Administration, Washington, D.C.: "Tactile Reading Device Studies at Stanford Research Institute"
	Film, "Microelectronic Reading for the Blind," shown by Dr. Linvill at 6th Technical Session on Reading Machines for the Blind
May 17	Presentation by Dr. Bliss at Computers and Psychobiology Workshop, U.S. Naval Postgraduate School, Monterey, California: "Visual-Tactual Sensory Communications"
June 13-17	Presentation by Mr. K. Gardiner of Stanford Research Institute of two papers[2] at International Conference on Sensory Devices for the Blind, sponsored by St. Dunstan's, London

[1] Publication 3
[2] Publications 15 and 16

1966 (Cont.)

June 30 — Film, "Microelectronic Reading for the Blind," shown at Conference of American Association of Instructors for the Blind, Salt Lake City

Sept. 12 — Presentation by Dr. Linvill at 15th General Assembly of the Scientific Radio Union (URSI), Munich: "Review of Advances in Microelectronics" (including film)

1967

May 16 — Presentation[1] by Dr. Linvill at National Telemetering Conference, San Francisco: "Generation of Tactile Facsimiles for Blind Reading"

1968

Oct. 2 — Presentation[2] by Dr. Linvill at Government Microcircuit Applications Conference, Washington, D.C.: "Phototransistor Operation in the Charge Storage Mode"

Nov. 21-22 — S-2 reading aid presented by Drs. Linvill and Bliss, demonstrated by Candy Linvill at Office of Education, Social Rehabilitation Services, and Office of Naval Research, Washington, D.C.

1969

Feb. 19 — Presentation[3] by Dr. Meindl at International Solid-State Circuits Conference, Philadelphia: "Integrated Electronics for a Reading Aid for the Blind" (Outstanding Paper Award)

Demonstration of reading aid by Candy Linvill for audience of 850 at above conference

Feb. 20 — Stanford University News Release

Apr. 3-4 — Tactile Displays Conference at Stanford Research Institute - Presentations: J.C. Bliss, "Optical-to-Tactile Image Conversion for the Blind"[4]; J.C. Taenzer, "Visual Word Reading"[5]; C.H. Rogers, "Choice of Stimulator Frequency for Tactile Arrays"[6]

Reading aid demonstrations by Robert Stearns and Candy Linvill at above conference

Stanford Research Institute Press Release

July 24 — Presentation[7] by Dr. Meindl at 8th International Conference on Medicine and Biology in Engineering, Chicago: "A Reading Aid for the Blind Using Integrated Electronics"

Aug. 6 — Presentation[8] by Dr. Bliss at Joint Automatic Control Conference, University of Colorado, Boulder, Colorado: "An Information Processing Model for Tactile Perception"

Aug. 11 — Article with picture of "pancake" prototype reading aid in Medical News section of Journal of the American Medical Association: "Device Opens Books to the Blind" (pp. 851-2)

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[1] Publication 19
[2] Publication 29
[3] Publication 34
[4] Publication 47
[5] Publication 48
[6] Publication 49
[7] Publication 38
[8] Publication 40

Aug. 27	Presentation by Dr. Bliss at Association for Computing Machinery National Conference and Exposition, San Francisco: "Visual Prosthesis and Information Processing Technology"
Sept. 19	Story with picture of the S-5 reading aid and Candy Linvill in TIME magazine: "Replacing Braille?" (p. 52)
Sept. 25	Lecture by Dr. Bliss at University of California, Berkeley: "Visual Prosthesis I"
Oct. 2	Presentation by Dr. Bliss of status of Stanford-SRI reading projects at meeting of National Academy of Engineering Subcommittee on Sensory Aids, Washington, D.C.
Dec. 18	Talk by Dr. Brugler on direct translation reading aid at meeting of Lions Club, San Jose, California
Dec. 26	Short film, "The Optacon Reader," made in September 1969 by CBS Television News shown on Walter Cronkite Program (commentator: Bill Stout)

1970

January	Interview article in Stanford Engineering News: "The Optacon Illustrates Research Objectives at Stanford"
Jan. 9-10	Demonstration of reading aid by Candy Linvill at the Senator Criss Cole Governor-for-a-Day Program, Austin, Texas
Feb. 12-15	Public exhibit ("Exploratorium") at Palace of Arts and Sciences, San Francisco: Display booth manned by Stanford engineering students who instructed blind visitors in use of reading aid
	Stanford Research Institute Press Release
Feb. 20	Presentation[1] by Mr. Plummer at IEEE International Solid-State Circuits Conference, University of Pennsylvania: "MOS Electronics for a Reading Aid for the Blind"
Apr. 23	Participation by Dr. Bliss[2] as panel member in forum sponsored by American Foundation for the Blind, Ambassador Hotel, Los Angeles: "The Blind in the Age of Technology: A Public Discussion"
May 9	Talk and demonstration by Dr. Bliss and Miss Weihl at Meeting of the Visually Handicapped Section, Council for Exceptional Children (California State Federation), Palo Alto, California: "The Optacon: Reading Aid for the Blind"
June 18	Presentation[3] by Mr. Salsbury at Solid State Sensors Symposium, Minneapolis: "A Monolithic Image Sensor for a Reading Aid for the Blind"
June 19	Talk by Dr. Bliss at Institute for Parents of Young Visually Handicapped Children, California School for the Blind, Berkeley, Calif.: "The Optacon: Present Status and Speculations for the Future"

[1] Publication 45
[2] Publication 54
[3] Publication 50

July 2	Talk and demonstration by Dr. Linvill and Candy Linvill at the Biennial Conference of the Association for Education of the Visually Handicapped, New Orleans
July 15	Talk and demonstration by Dr. Linvill and Candy Linvill at the National Convention of the American Council of the Blind, Oklahoma City
Aug. 18	Keynote Address[1] by Dr. Linvill at International Conference on Microelectronics, Circuits, and System Theory, University of New South Wales, Sydney, Australia: "Harnessing New Technology to Society's Needs Through the Industry-University-Government System" (Demonstration of Optacon by Candy Linvill)
Aug. 29	Interview of Dr. Linvill and Candy for Australian newspapers and television
Sept. 10	Presentation[2] by Dr. Linvill at International Conference on Circuit and System Theory, Kyoto, Japan: "The Optacon--A Reading Aid for the Blind Employing Integrated Circuits" (Demonstration of Optacon by Candy Linvill)
Sept. 11	Demonstration of Optacon by Candy Linvill at Hitachi Central Research Laboratories, Tokyo
November	Optacon Newsletter No. 1 distributed
Nov. 18	Presentation[3] by Dr. Meindl at 23rd Annual Conference on Engineering in Medicine and Biology, Washington, D.C.: "A Reading Aid for the Blind Using MOS Electronics"
Dec. 3	Presentation[4] by Dr. Bliss at Council for Exceptional Children Conference on Instructional Technology for the Handicapped, San Antonio: "Man-Machine Interfaces in Training Optacon Readers"
Dec. 28	Optacon briefly described on 2-hour ABC Television Special narrated by Frank Reynolds concerning changes in American living during 1960's and prospects for the 1970's

1971

Jan. 30	Lecture and demonstration by Dr. Bliss at Northern California Ninth Regional Meeting for the Visually Handicapped, Novato, California: "The Optacon"
Feb. 13	Demonstration of the Optacon by Dr. Brugler at Curriculum Fair, Portland State University, Portland, Oregon
Feb. 14	Televised interview by Jon Tuttle of KGW-TV Portland with Dr. Brugler shown on Sunday evening news broadcast and on Monday (Feb. 15) at noon
Feb. 18	Presentation[5] by Mr. R. Nordstrom at IEEE International Solid-State Circuits Conference, University of Pennsylvania: "The Field-Effect Modified Transistor: A New Compound Transistor"

1 Publication 51
2 Publication 52
3 Publication 57
4 Publication 58
5 Publication 62

Feb. 19	Public lecture by Dr. Linvill at University of Genoa, Italy: "The Optacon" (Demonstration of Optacon by Candy Linvill)
Mar. 13	Demonstration of mathematical use of the Optacon by Mr. Schoof at 12th Annual Conference of California Transcribers and Educators of the Visually Handicapped, Inc., San Diego, California (First conference showing of the new, compact Optacon)
Mar. 24	Talk by Dr. Linvill in the Keynote Session of the IEEE International Convention, New York City: "Implementing the Technological Attack on Rehabilitation and Medical Problems"
Mar. 30	Demonstration of Optacon by Candy Linvill at National Physical Laboratory, Jerusalem
Apr. 18-24	Films "The Optacon Reader" and "Reading Aid" (starring Robert Stearns, computer programmer at Stanford Research Institute) shown at CEC International Convention, Miami, Florida
Apr.	Lecture by Miss Weihl at University of Cincinnati (Helen G. Levine Lecture Series): "Now Blind Persons Can Read Print"
Apr. 24	Presentation and demonstration of Optacon by Dr. Linvill and Candy Linvill for the Deutscher Blindenverband in Bonn (Bad Godesberg), Germany
May 22-24	Demonstrations by Dr. Bliss, Miss Weihl and Mr. Schoof at Cleveland Sight Center Open House, Cleveland, Ohio
June 8	Two demonstrations by Dr. Brugler and Mr. Stearns at Jewish Guild for the Blind in New York City, sponsored by New York State Commission for the Blind and Visually Handicapped
June 24	Demonstration of Optacon by Candy Linvill at American Foundation for Overseas Blind in Paris
June 29	Demonstration of Optacon by Candy Linvill at St. Dunstan's, London
July 15-16	Lecture by Dr. Linvill at Institute of Electronic Technology (invitation of Polish Academy of Sciences), Warsaw: "Integrated Circuits in the Optacon"
	Demonstration of Optacon by Candy Linvill at Institute for the Blind in Warsaw; newspaper coverage and filming for Polish television science program
Sept. 9	Talk on the Optacon by Dr. Bliss at NASA National Conference on New Technology for the Neurologically Handicapped, Moffett Field, California
Sept. 23	Industrial Research 100 Award for S-15 Optacon as one of 100 most significant new technical products of the year accepted by Dr. Bliss at Museum of Science & Industry, Chicago (Optacon exhibited from Sept. 24 to Oct. 22)
Oct. 12	Presentation[1] by Dr. Plummer at International Electron Devices Meeting, Washington, D.C.: "High Voltage Monolithic MOS Drive Arrays"

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[1] Publication 70

1971 (Cont.)

Oct. 18	Demonstration of Optacon by Candy Linvill at Berufsforderungswerk, Heidelberg, Germany
Oct. 20	Presentation[1] by Dr. Brugler at Eurocon 71, Lausanne, Switzerland: "Technology for the Optacon, A Reading Aid for the Blind"
Oct. 22	Demonstration of Optacon by Candy Linvill at University Eye Clinic Lecture Hall, Bern, Switzerland
Oct. 25	Talk by Dr. Bliss at 50th Anniversary Meeting of the American Foundation for the Blind, New York City: "Sensory Supplementation: Reading" (Optacon demonstrated by Mr. Vito Proscia on five television stations)
November	Optacon Newsletter No. 2 distributed
Nov. 11-12	Participation by Drs. Linvill and Bliss in Conference on Evaluation of Sensory Aids for the Visually Handicapped, Committee on Prosthetics Research and Development, National Academy of Sciences, Washington, D.C.

1972

January	Film "The Optacon Story" made in Cleveland
Jan. 28-29	Demonstrations of the Optacon by Dr. Brugler and Candy Linvill at an information exchange fair, Northwest Rehabilitation Center for the Blind, Seattle, Washington
Mar. 17	Lecture by Dr. Bliss at Berufsforderungswerk, Heidelberg: "The Optacon Story"
Mar. 28	Lecture by Dr. Bliss at the Handicapped Institute of Stockholm, Sweden: "The Optacon Story"
Apr. 20	Presentation[2] by Dr. Berger at International Symposium on Circuit Theory, Hollywood, California: "Circuits for a Reading Aid for the Blind"
May 4-5	Demonstrations by Dr. Linvill and Mr. Schoof of the Optacon in conjunction with a computer terminal at IBM, Bethesda, Maryland, and at 25th Meeting of the President's Committee on Employment of the Handicapped, Washington, D.C.
June 2	Lecture by Dr. Linvill at University of California, Santa Barbara (Dept. of Mechanical Engineering): "Integrated Circuits in the Optacon" (Demonstration of Optacon by Mr. Schoof)
Sept. 20-21	Demonstrations by Mr. Schoof of the Optacon in conjunction with the HP-35 calculator at Solid-State Affiliates Conference, Stanford University
Oct. 6	Presentation[3] by Dr. Berger at 10th Allerton House Conference, University of Illinois: "Integrated Circuits for Bio-Medical Applications"
Oct. 16	Demonstration of Optacon by Mr. Schoof at Stanford for Mr. Richard Reizner (Voice of America)

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[1] Publication 71
[2] Publication 76
[3] Publication 78

1972 (Cont.)

Oct. 23	Stanford University News Release
Oct. 31	Demonstration by Mr. Schoof at Santa Clara County Courthouse, San Jose, California, of the Optacon's use in casting a ballot without sighted assistance
November	Optacon Newsletter No. 3 distributed
November	First appearance of advertisement (Scientific American) showing Mr. Schoof using the Optacon with the HP-35 calculator
Nov. 7	Television news coverage of Mr. Schoof at the polls
Dec. 4	Demonstration by Mr. Schoof at Association for Computing Machinery Conference, Anaheim, California, of use of a modified Optacon to read video computer printouts
	Stanford University News Release

1973

Feb. 4	Presentation by Dr. Linvill at 1973 Science Writers Seminar, Universal City, California, sponsored by Research to Prevent Blindness, Inc.: "The Optacon--A product of Advanced Technology to Aid the Blind"

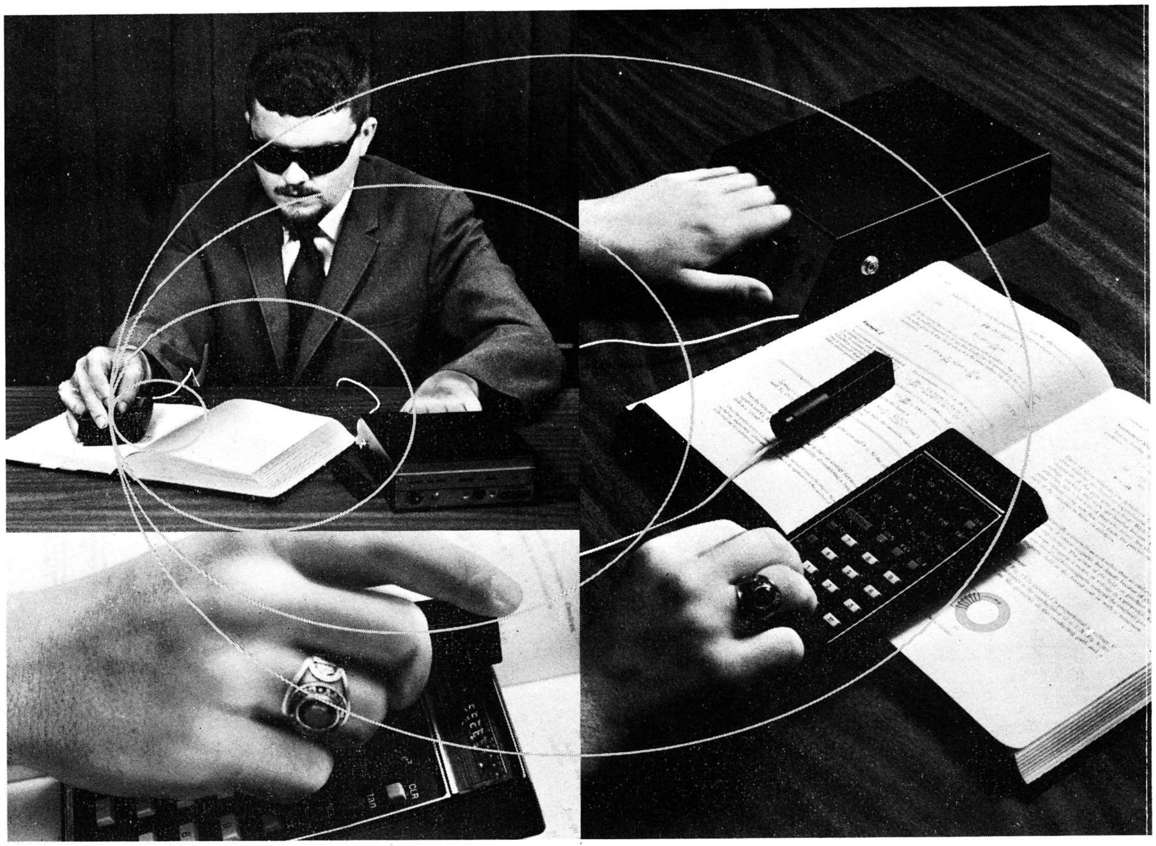
APPENDIX VI

HEWLETT-PACKARD ADVERTISEMENT

Photograph of Hewlett-Packard's November 1972 ad (Scientific American, Science Magazine) showing use of the Optacon with the HP-35 pocket calculator:

Some things are changing for the better.

Many people know us as an instrument manufacturer: we make more than 2,000 products for measurement, test and analysis. Others know us as a computer company: more than 10,000 own our calculators and computers. We prefer to think that our business is to serve your measurement and computation needs.



A better chance for the blind.

When we took this picture of Loren Schoof, he was reading the answer to a complex problem that he had just worked out on the HP-35 Pocket Calculator. Unassisted. And Loren is blind.

There was no magic about it. Only the technological wizardry of the Optacon, a portable reading aid for the blind developed at Stanford University, added to the computational capability of the HP-35. The Optacon converts the visual image of a printed character or illuminated display directly into a tactile image that can be felt with one finger.

A miniature camera activates an array of 144 tiny rods, each one vibrating individually, re-creating the image seen by the camera. With his index finger on the vibrating rods as he moves the camera across the calculator display, Loren feels exactly what the camera sees.

Besides giving him computational capability with the HP-35, the Optacon has given Loren access to a world of information beyond the reach of braille editions.

Loren can "read" practically everything we can—books, class notes, phone directories. With the HP-35 Calculator, the result is classically synergistic; log, trig, exponential and mathematical functions are available with single keystrokes, intricate equations are reduced to a logical series of keystrokes without the need to record intermediate steps, and the answers are accurate to 10 digits. Let no one tell you that Loren Schoof is not mathematically competitive in the sighted world.

The HP-35 is also proving a boon to many thousands of sighted scientists and engineers who are using it in the lab and on the road. Here are some additional reasons why: ten-digit accuracy between 10^{-99} and 10^{99}, automatic decimal point positioning with floating point or scientific notation, operational stack of four registers plus storage register, blanking of insignificant zeroes, battery or AC operation, nine-ounce portability and advanced computational capability. All for a price, in the U.S., of $395 (plus tax).

We'll be glad to send you a full description of the HP-35 and forward your request for information on the Optacon to its manufacturer, Telesensory Systems, Inc.

APPENDIX VII

RELATIONSHIP OF TELESENSORY SYSTEMS, INC. TO THE OPTACON RESEARCH GROUP AT STANFORD UNIVERSITY

In 1971 after the need was apparent for more Optacons than could be produced at Stanford University and at the Stanford Research Institute, Telesensory Systems, Inc. was incorporated. Dr. J.C. Bliss is President, Dr. J.S. Brugler is Vice-President, and in addition to them, Professors Meindl and Linvill joined the Board of Directors. TSI's first order was in the form of a contract with the Office of Education for the production of 50 Optacons for a field trial. Concurrently, orders for devices were taken from other organizations in the United States and Europe.

The Optacon is based in part upon a patent, No. 3,229,387, issued to J.G. Linvill in January 1966. The idea was conceived while Linvill was under support of the Office of Naval Research. Consequently, the United States Government holds a non-exclusive, irrevocable, non-transferable, royalty-free license to practice the invention. The patent now is held by Telesensory Systems, Inc.; it is meaningful only for commercial application.

The intent of the principal investigator and his colleagues at Stanford University is to develop useful devices for the blind and to understand the new principles in technology and human performance that our studies reveal. In the environment of the University any part of our research must be open to discussion with any interested visitor. The knowledge contributions are the basis of dissertations which become part of the open technical literature. Of course, results are available immediately to TSI, as they are to any other developer who can better provide devices for the blind.

TSI is a commercial enterprise. It is providing unique goods and services to the blind, primarily through governmental and other agencies. Successful distribution of the Optacon, as well as other such devices, requires a number of capabilities and functions. It requires successful production, the technique and management that must accompany it, and promotion and service as well. The company must provide a basis for compensation of employees, reward for the demands and risks of management and investment.

The principal investigator foresees reward for outstanding productivity to TSI, its employees and stockholders, in their provision of high-technology devices for the blind. He believes that the implicit liaison of university, government and industry in the application of technology to integrate the blind with the production of the sighted world is an operation in which all constituencies gain.

APPENDIX VIII

REPRESENTATIVE OPTACON PURCHASERS

U.S. Government

U.S. Office of Education
Bureau of Education for the Handicapped
Washington, D.C.

Library of Congress
Division for the Blind and Physically Handicapped
Washington, D.C.

Veterans Administration Hospital
Prosthetics Center
New York, N.Y.

Internal Revenue Service
Washington, D.C.

U.S. Department of Agriculture
Washington, D.C.

National Organizations

The Seeing Eye, Inc.
Morristown, New Jersey

National Center for Deaf/Blind Youths and Adults
New Hyde Park, N.Y.

Schools for the Blind and Special Educational Services

Hadley School for the Blind
Winnetka, Illinois

Tennessee School for the Blind
Nashville, Tennessee

Olympia Vocational Technical Institute
Olympia, Washington

San Diego City Schools
Student Services Division
San Diego, California

Cincinnati Public Schools
Special Education
Cincinnati, Ohio

Oakland Unified School District
Oakland, California

Azusa Unified School District
Azusa, California

Monroe School
Campbell, California

State and City Agencies

Massachusetts Commission for the Blind
Boston, Massachusetts

New York Association for the Blind
New York, N.Y.

Albany Association for the Blind
Albany, N.Y.

Cleveland Society for the Blind
Cleveland, Ohio

Arkansas Enterprises for the Blind
Little Rock, Arkansas

Services for the Blind
Seattle, Washington

Greater Pittsburgh Guild for the Blind
Bridgeville, Pennsylvania

State of Iowa Commission for the Blind
Des Moines, Iowa

Michigan Department of Social Services
Rehabilitation Services
Detroit, Michigan

Ohio Rehabilitation Services Commission
Columbus, Ohio

West Virginia Division
Vocational Rehabilitation
Charleston, West Virginia

Commonwealth of Kentucky
Department of Education
Rehabilitation Materials Unit

Palo Alto Society for the Blind
Palo Alto, California

Universities and Research Institutes

University of Pittsburgh
Pittsburgh, Pennsylvania

Johns Hopkins University
School of Medicine
Baltimore, Maryland

West Virginia University
Morgantown, West Virginia

University of Cincinnati
Department of Electrical Engineering
Cincinnati, Ohio

Case Western Reserve University
Cleveland, Ohio

Universities and Research Institutes (Cont.)

Franklin Institute for Research Labs
Philadelphia, Pennsylvania

Smith-Kettlewell Institute of Visual Sciences
San Francisco, California

Bell Laboratories
Murray Hill, New Jersey

Foreign

Berufsforderungswerk Heidelberg
Heidelberg, West Germany

Istituto di Elettrotecnica
University of Genoa, Italy

Dept. of Speech Communication
Royal Institute of Technology (KTH)
Stockholm, Sweden

University Eye Clinic
Lund, Sweden

De Blindas Forenings
Enskede, Sweden

De Blindas Vanner
Goteborg, Sweden

Research Centre for the Education of the Visually Handicapped
University of Birmingham, England

St. Dunstan's for Men and Women Blinded on War Service
London, England

Victoria Institute for the Blind
Melbourne, Victoria, Australia

Statens Institut for Blinde og Svagsynede
Hellerup, Denmark

Jewish Institute for the Blind
Jerusalem, Israel

Individual

Computer programmers, college students, lawyers, teachers, writers, radio announcers, executives and others (approximately 35 to date)